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Response of Crude Oil Slicks to Dispersant Treatment at Sea, 1979 Tests

JBF Scientific Corp., Wilmington, MA

Prepared for

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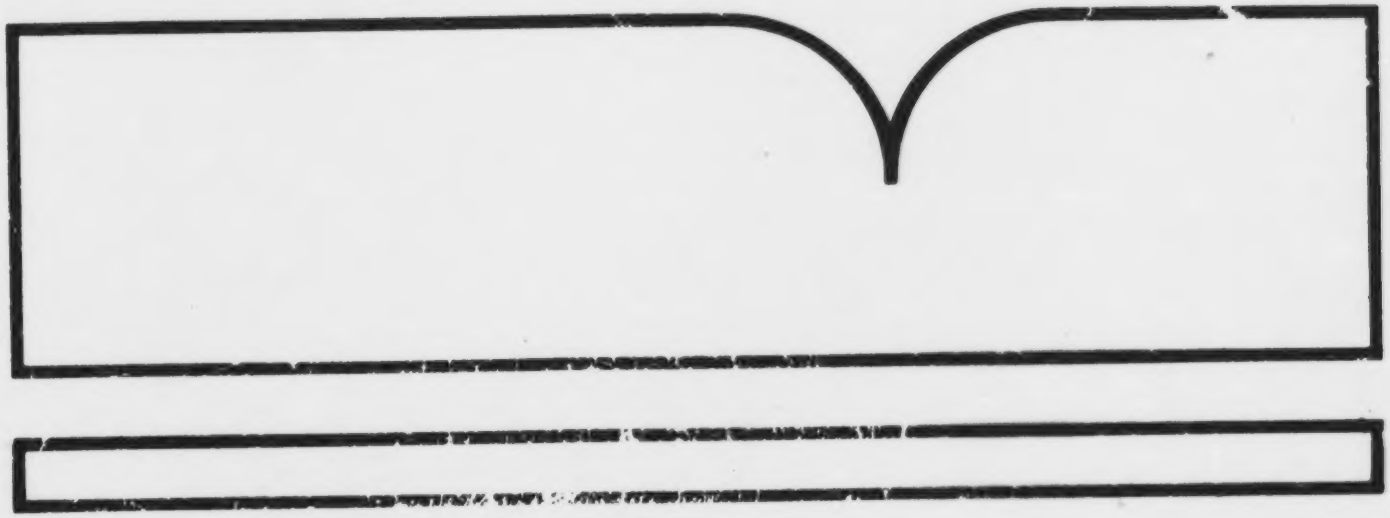

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FINAL REPORT

RESPONSE OF CRUDE OIL SLICKS TO DISPERSANT TREATMENT AT SEA

1979 TESTS

by

JBF Scientific Corporation
Wilmington, Massachusetts 01887

Grant No. R806056

Project Officer

Leo T. McCarthy, Jr.
Oil and Hazardous Materials Spill Branch
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

This study was conducted
in cooperation with
American Petroleum Institute
Task Force on Dispersed Oil
Washington, D.C. 20037

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
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16. ABSTRACT

Four small research oil spills (3.54 m^3 each) were made to compare the physical and chemical behavior of crude oils on the sea with and without dispersant treatment. Work was performed 90 km southeast of New York Harbor under a research ocean dumping permit from the U.S. Environmental Protection Agency (EPA). Each spill was made from a research vessel and was tracked by vessel and aircraft for several hr. Two crude oils were used; one spill of each was treated with dispersant after 30 min, and one was allowed to weather naturally as an experimental control. A self-mix dispersant was sprayed on the two treated slicks from a helicopter that had been fitted with a spray system delivering droplets whose mean diameter was approximately 2 mm. More than 750 samples of background water, water under the slicks, and surface water were taken for chemical analysis. Sampling continued for 6 to 7 hr after each spill. Aerial photographs were taken, and representative photographs are presented in this report. Currents and winds were measured, leading to interpretation of physical transport of the oils. This report complements earlier work performed in 1975 and 1978.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This report describes field tests in which a chemical dispersant was applied to controlled oil spills. The findings provide information about the fate of spilled oil in the treated and untreated conditions.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

Four small research oil spills (3.54 m^3 each) were made to compare the physical and chemical behavior of crude oils on the sea with and without dispersant treatment. Work was performed 90 km southeast of New York Harbor under a research ocean dumping permit from the U.S. Environmental Protection Agency (EPA). Each spill was made from a research vessel and was tracked by vessel and aircraft for several hr. Two crude oils were used; one spill of each was treated with dispersant after 30 min, and one was allowed to weather naturally as an experimental control. A self-mix dispersant was sprayed on the two treated slicks from a helicopter that had been fitted with a spray system delivering droplets whose mean diameter was approximately 1 mm. More than 650 samples of background water, water under the slicks, and surface water were taken for chemical analysis. Sampling continued for 6 to 7 hr after each spill. Aerial photographs were taken, and representative photographs are presented in this report. Currents and winds were measured, leading to interpretation of physical transport of the oils. This report complements earlier work performed in 1975 and 1978.

Chemical analyses and visual observations showed that the dispersant-treated oil entered the water to a much greater extent than the untreated oil. Differences between the two crude oils in their response to dispersant treatment were not apparent, based on amounts of oil found in the water. In the plumes of dispersed oil, zones of high concentration were consistently found beneath the upwind and downwind portions of the visible surface oil, with lower concentrations in the middle.

This report was submitted in fulfillment of EPA Grant No. R806056 by JBF Scientific Corporation and the American Petroleum Institute under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period January 1, 1979 to December 19, 1980, and work was completed as of December 19, 1980.

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Many extraordinary efforts were made by API Task Force members and EPA staff to assist in the successful execution of this study. Clayton McAuliffe of Chevron Oil Field Research Company worked with JBF on many aspects of test design and provided the subsurface sampling system that was used. In addition, he took primary responsibility for guiding sampling vessels from the command aircraft, thus freeing the JBF Project Manager for guiding photographic efforts and for careful logging of events.

Within JBF, acknowledgment must be made of Stephen Greene's persistence and problem-solving in accomplishing the work aboard ship. Jaret Johnson was Project Manager.

SECTION 1

INTRODUCTION

This is the third report on a series of East Coast open ocean oil spill experiments to determine the physical and chemical behavior of crude oils spilled at sea. Tests performed in 1975 were sponsored by the American Petroleum Institute (API). The U.S. Environmental Protection Agency (EPA) became a partial sponsor, with API, for tests performed in 1978 and 1979. This report discusses the 1979 tests. During 1978 and 1979, ocean tests with some similarity to these East Coast tests were performed off the California coast. Information on all of these test programs is summarized below:

- Four research spills were studied in the Gulf of Maine in 1975, each including aerial photography, navigational tracking, and sampling of water and surface oil. These studies were described in API Publication 4290[1] and in papers by McAuliffe[2], and Johnson, McAuliffe, and Brown[3].

- Several research spills were studied off Southern California in 1978. Some of these were tracked scientifically, as above, and others were subjected to a variety of attempts at skimming or dispersant application[4].

- Four research spills were studied in the outer New York Bight in 1978, each of which was treated with a dispersant. The final report is complete[5], and a paper has been published recently[6].

- Several research spills were studied off Southern California in 1979. These are described in a paper that will be presented at the 1981 Oil Spill Conference[7].

- Four research spills were studied in the outer New York Bight in 1979. These are the subject of this report.

PURPOSE

The 1979 East Coast tests were made to augment earlier data on the physical and chemical behavior of two crude oils spilled at sea, as affected by the application of a dispersant. Independent variables in this experiment were oil type and whether dispersant was applied. So that comparisons could be made with the 1975 and 1978 tests, the same crude oils were used. Differences from earlier tests included the time of dispersant application,

the dispersant-to-oil dose rate, and the volume of oil spilled. In addition, biological tests were performed inside and outside the spill areas by the University of Southern California (USC).

SCOPE

This report describes the methods, observations, results, and conclusions of the four research oil spill experiments conducted by JBF Scientific Corporation in the outer New York Bight in 1979. Although JBF closely coordinated its efforts with those of USC, the biological results and their reporting are outside the scope of this report. All data and interpretations relating to physical and chemical fate are provided here.

SECTION 2

CONCLUSIONS

Average total extractable organics concentrations under the dispersed slicks at 1, 3, 6, and 9 m were, respectively: La Rosa - 1.9, 1.5, 0.9, and 0.2 mg/ℓ; Murban - 16.3, 0.7, 0.1, and 0.1 mg/ℓ. Because the dispersant:oil volume ratio was about 1:9.4, the above concentrations are probably 10 to 11% dispersant (i.e., when extractable organics are 1 mg/ℓ, the dispersant should be 0.1 mg/ℓ and the oil 0.9 mg/ℓ).

Extractable organics concentrations under the untreated slicks were lower than those under treated slicks, and approximate computations indicated that less than 5% of the untreated oil had entered the water. For the treated slicks, 50 to 90% of the oil was found in the water column.

The primary differences between the slicks dispersed at 30 min (1979) and those dispersed in less than 10 min (1978) were that the 1979 dispersant effects were visually less pronounced, and that the plume shape was more complex in 1979. Sample analyses consistently showed that the plumes in 1979 had lower oil concentrations in the center than at the upwind and downwind areas. The 1978 plumes had only one zone of high concentration. This difference is probably caused by the movement of surface oil away from the point of discharge in the 1979 tests before the dispersant was applied.

In general, extractable organics concentrations and depth of penetration into the water were similar to those observed in the immediately dispersed spills of 1978. In 1979, however, the double areas of high concentration in each plume resulted in a finding of more oil in the water. Thus, the larger amount of oil spilled in 1979 resulted in a larger volume of water with a given oil concentration rather than in higher concentrations.

Low-molecular-weight (C_1 to C_{10}) hydrocarbon concentrations in the samples analyzed were above background in only 21% of the samples analyzed. Several of the samples with elevated concentrations of these volatile compounds were taken beneath untreated slicks where the water's total oil content was relatively low.

SECTION 3

RECOMMENDATIONS

Data from this report should be compared with data from laboratory effectiveness tests. If the laboratory tests are valid and if reliable scaling relationships can be derived, other oils and other dispersants should be tested. Thus a data base could be developed to guide dispersant selection and fate predictions for accidental spills.

Sampling of water beneath oil spills should include stations well outside the perimeter of the visible oil so that the edges of the plume can be defined unambiguously.

The cause for double zones of high concentration in the dispersed oil plumes should be investigated. This work could probably be done in a tank or pool, and should aid future efforts at modeling and predicting the effects of dispersant application.

Findings of this report and that on the 1978 tests should be coordinated wih the biological studies for both test series in a unified summary document.

SECTION 4

EXPERIMENTAL METHODS

PARTICIPATING ORGANIZATIONS

After JBF and the API had contracted for this project, the U.S. Environmental Protection Agency's Office of Research and Development (EPA/ORD) became sufficiently interested to participate in funding the project by means of a grant to the API for part of the cost. In addition to the research interest by EPA/ORD, EPA's Region II was involved in the regulatory function of reviewing JBF's application for a research permit under PL92-532, the Marine Protection, Research, and Sanctuaries Act of 1972.

These and other relationships among the administrative and technical participating organizations are outlined in Figure 1. Some of the groups shown in Figure 1 will be discussed later in this section with regard to test methods; other groups' activities are described here.

Research Permit (EPA Region II)

An application for a research permit was submitted to the Surveillance and Analysis Division, Marine Protection Program, of EPA Region II on July 19, 1977. A request for clarification and expansion on 18 issues was sent to JBF by Region II on October 27, 1977. JBF's response, amending the original application, was sent to Region II on December 19, 1977. Permit No. II-MA-143-Research was granted by Region II, after public notice and comment, on June 30, 1978. The permit's effective period was October 1, 1978 through March 31, 1980. JBF's work in both 1978 and 1979 was under this permit.

Remote Sensing (NASA)

The National Aeronautics and Space Administration (NASA) is developing technology to monitor various environmental phenomena, including oil spills, from satellites. Development and testing of the equipment is being performed from aircraft. JBF learned of NASA's desire to monitor planned oil spills, and contacted the NASA Langley Research Center in August 1978 to discuss possible cooperation. Subsequent discussions led to extensive efforts at remote sensing on the 1978 test spills, involving up to four aircraft under NASA's guidance. A more limited remote sensing effort was made for the 1979 tests, with one NASA aircraft.

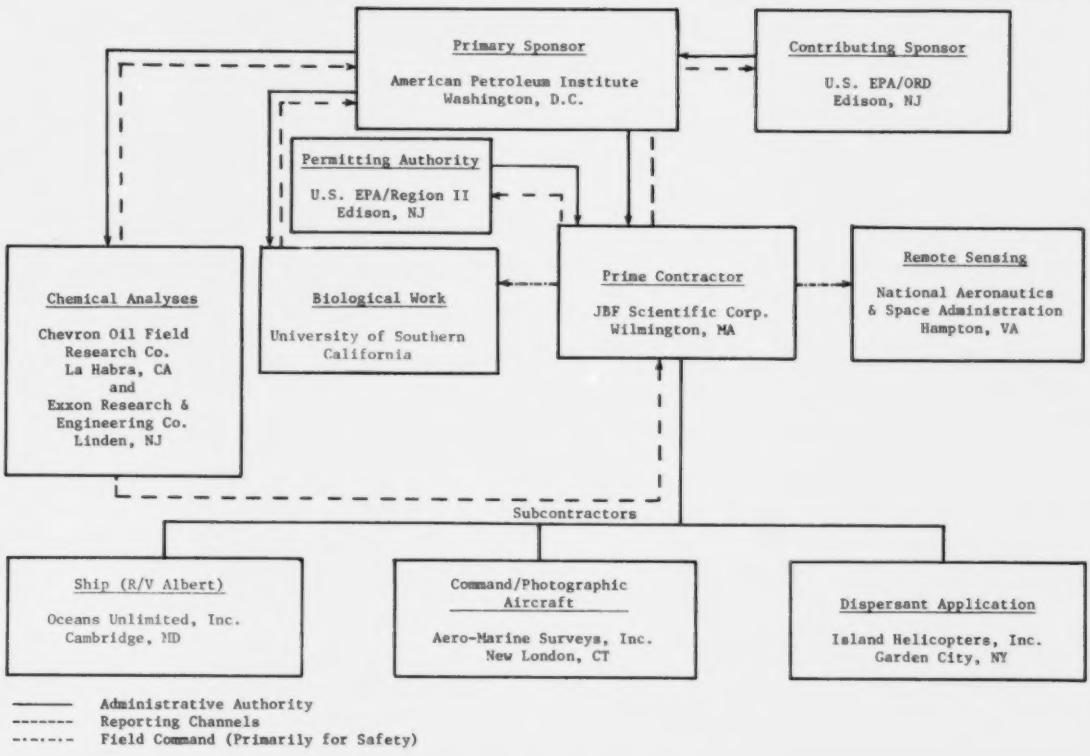


Figure 1. Relationships among participating organizations.

Communications

Three independent modes of communication were used: aircraft VHF-AM and two UHF systems. One UHF system (provided for these tests by Texaco) connected the command aircraft with the two ships and with the helicopter for overall coordination. The other UHF system (provided by Chevron) was used primarily for the detailed vectoring of the ships to the sampling stations.

SPILL LOCATIONS AND GENERAL CONDITIONS

The area permitted for the tests, and the actual locations of the four test spills in 1979, are shown in Figure 2. These sites were selected because their distance from shore and prevailing currents made it unlikely that any oil would approach shore. They are farther offshore than the 1978 test sites because interference with NASA's remote sensors was present during 1979 at the 1978 test sites. Finally, no spills were made when wind was blowing toward shore.

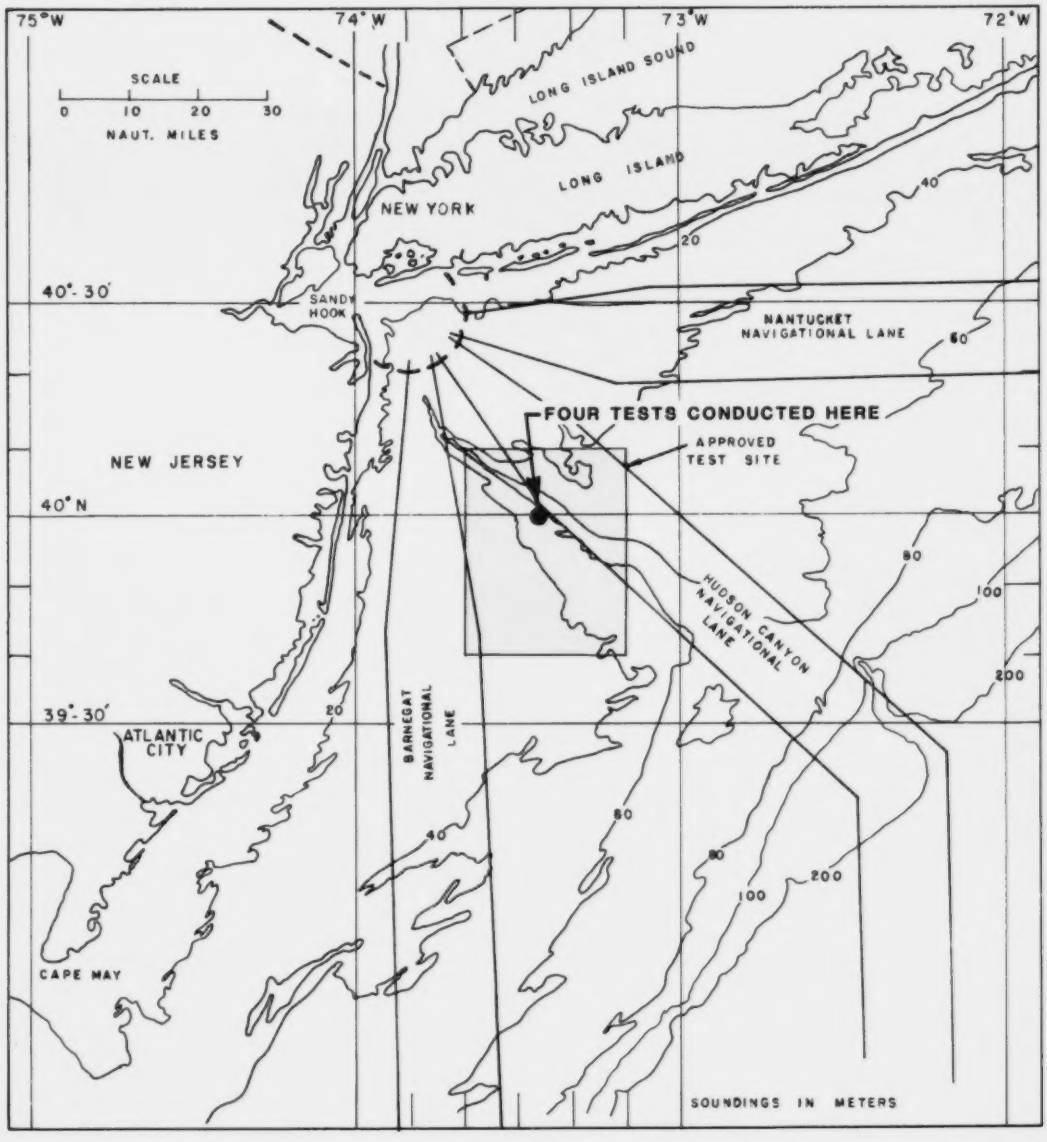


Figure 2. Chart showing test area.

Table 1 shows the general experimental and environmental conditions for the tests. These conditions appear sufficiently similar that weather is not considered a variable affecting test results.

TABLE 1. GENERAL EXPERIMENTAL CONDITIONS

Date	Wind Speed (m/sec)	Seas (m)	Water Temp. (°C)	Air Temp. (°C)	Oil and Treatment	Spill Time (EDT)	Dispersant Spraying Time (EDT)
Oct. 22	0-5	0.3-1.6	16	18-21	Murban, Not Treated	0848-0852	
					Murban, Dispersed	1019-1024	1048-1100
Oct. 23	5-7.5	0.6-1.6	16	16-21	La Rosa, Not Treated	0845-0852	
					La Rosa, Dispersed	1127-1134	1205-1223

On both test days, discharge of the second spill (the one to be treated) was timed so that the spray helicopter would arrive about 25 minutes later. The helicopter and the control aircraft thus had some time to view the slick and coordinate the approach to treatment before the scheduled beginning of spraying at 30 minutes.

On October 22, 1979 (Murban spills), weather and sea conditions were ideal, allowing the entire operation to proceed on schedule. On the next day (La Rosa spills) after the control spill was made, the ceiling and visibility rapidly diminished on Long Island. A delay in releasing the second spill resulted because the dispersant-spraying helicopter was unable to fly to the shoreline (test site weather remained good). The Long Island weather improved late in the morning, and the second La Rosa spill occurred 2.7 hours after the first spill, rather than the planned 1.3 hours. Site conditions did not change during the test period, so there should be no scientific effect of this delay on the test results.

GENERAL OPERATIONS

Navigation

Both the Albert and the control aircraft used Loran-C for navigation. Positions were recorded for all sampling stations, for all aerial photographs, and for any other events of significance. The precision of the Loran-C readings is approximately ± 100 ft in the test area.

Current Measurement

Currents were measured by tracking drogues from the ship and from the air. Loran-C positions and times were plotted in the office to derive current vectors. These drogues were of the customary four-vane configuration, presenting a square drag area to the water (1.2 m on a side), with a small staff and flag above the waterline for ease in sighting (Figure 3). The drogues' buoyancy was such that they followed currents approximately 1 to 2 m below the surface.

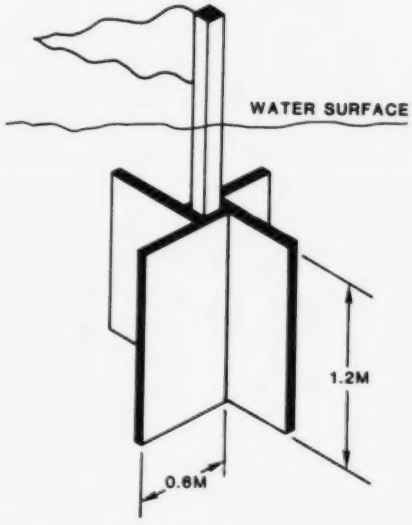


Figure 3. Sketch of four-vane drogue.

Air Control and Photography

The aircraft for operational control and photography was provided by Aero-Marine Surveys, Inc., of New London, CT. A Cessna Model 337G Skymaster was used, carrying the Aero-Marine Surveys pilot and photographer, and the JBF Project Director. An API representative guided the research vessels to sampling stations, and the JBF Project Director guided the dispersant-spraying helicopter from this aircraft.

Vertical color photographs were made with a belly-mounted Hasselblad MK-70 mm camera. Color negative exposures were made on Kodak 8 Color Safety Film. A second camera recorded readings on a data panel for Loran-C position, time, altitude, and heading. Both cameras were activated simultaneously for each exposure. Altitudes for photography varied from 160 to 1300 m.

Spilling Oil

Each spill was 3.55 m^3 (935 gal) of one of the crude oils (Murban from Abu Dhabi and La Rosa from Venezuela). These were the same crudes used in the 1975 and 1978 test series.

Each spill was discharged from a 3.8 m^3 tank mounted on the stern of the research vessel through two 7.6 cm diameter hoses. Each hose was 7 m long, extending over the side to the water surface. The ends of the hoses were on floats, causing the oil to discharge horizontally on the water surface. This minimized both evaporation losses due to discharge above the water, and vertical descent of the oil into the water. The less viscous Murban (0.83 specific gravity, 39° API) discharged in approximately 5 min; the La Rosa (0.91 specific gravity, 23.9° API), in 7 min. All "time after spill" data in this report are based on the beginning of the spill. The research vessel was moved by its propeller during the spills, approximately 50 m crosswind so that the wind would not cause very narrow slicks. Thus, immediately after each spill, the crosswind dimension was approximately twice the dimension parallel to the wind.

Spraying Dispersant

A self-mix dispersant, suitable for application without added mixing energy (e.g., prop wash or breaker board agitation), was used for all tests.

When dispersant is applied from the air, care is required to produce droplets that are large enough not to drift from the target, but not so large that they plunge through the oil film or do not achieve even coverage of the area. Extensive discussions between JBF and Island Helicopters, Inc. led to a series of dry-land field tests during 1978 in which various spray nozzles, aircraft altitudes, and flight speeds were checked. Several members of the API Task Force on dispersed oil participated in these field tests. The result was the set of dispersant application specifications listed in Table 2. These specifications apply to both the 1978 and 1979 test series.

The treated slicks were allowed to weather for 30 min before treatment. At T+30 (30 min after beginning the spill), slick areas were approximately 2 ha (4.9 acres). The helicopter carried 379 ℓ (100 gal) of dispersant. Therefore, dose rates were 1:9.4 (volumetric) or 190 ℓ/ha (20 gal/acre) (areal).

TABLE 2. DISPERSANT APPLICATION SPECIFICATIONS

Aircraft:	Bell 206 B Jet Ranger
Spray System:	Belly-mounted Simplex unit with 10-meter boom mounted above skids
Nozzles: Type	Spraying Systems Co. No. D1256 Cone-type teejets
: Number	15
Mean Droplet Diameter:	Approximately 1 mm

For both tests, dispersant was discharged while the helicopter flew crosswind, with the wind from the port side of the helicopter. Close observation by the command aircraft and constant radio contact were used to guide the helicopter. As in the 1978 tests, the helicopter pilot was unable to discern the boundary between treated and untreated areas. However, the command aircraft with its higher altitude and observers with experience in similar operations was able to guide the spray helicopter. Even with this careful direction, there was some spraying outside the slick perimeters. This small amount of off-target spraying, along with some wind drift of dispersant, slightly reduced the amounts of dispersant applied to the oil slicks reported above.

SAMPLING AND SAMPLE HANDLING

Subsurface water column samples were taken at each station by an array of small submersible pumps, discharging through polypropylene tubing. The pumps' internals were of glass-filled polypropylene (Teel Model 1P681). Pumps were attached approximately 0.5 m below a floating 115 ℓ (30 gal) steel drum towed 3 m lateral to the bow the the research vessel. In this position, the ship's bow wave did not cause water mixing at the sample inlets. These were 1, 3, 6, and 9 m below the water surface, along a taut line suspending a 23 kg weight from the bottom of the float. The sample gear was lowered and removed from the water outside the slicks to avoid surface oil contamination. Surface samples were taken with a small bucket at all stations except those in untreated slicks.

Two types of samples were collected: one 1.5 ℓ sample in 1.9 ℓ (0.5 gal) flint glass jug, and completely filled 300 ml (10 oz) "soft drink" bottles with crown caps. Immediately after collection, 50 ml of distilled-in-glass carbon tetrachloride (CCl_4) was added to each 1.9 ℓ jug from an all-glass dispensing pipet. The jugs were sealed with teflon-lined metal

screw caps, and hand-shaken for about 10 sec to initiate the solvent extraction of organic matter including the dispersed oil. The CCl_4 also prevented bacterial degradation of the hydrocarbons. In the laboratory, the samples were shaken 2 min to complete the extraction.

Prior to sample collection, about 30 mg of mercuric chloride ($HgCl_2$) was added to each 300 ml bottle to prevent biodegradation prior to analysis. Each bottle was then flushed with reactor-grade helium and sealed with a crown cap (polyvinyl chloride seal). At time of sample collection, each bottle was uncapped, filled to within 3 mm of the top with simultaneous flushing by reactor-grade helium, and resealed with a crown cap. The small headspace minimized loss of volatile hydrocarbons to this gas space.

The sampling program was designed to obtain water samples at approximately equally spaced stations on transects through the surface slicks and emulsion plumes. Figure 4 is a schematic diagram of a typical sample run. A sampling run took about 45 min. The LORAN-C coordinates wre recorded at every sampling station. Sampling details are summarized in Table 3.

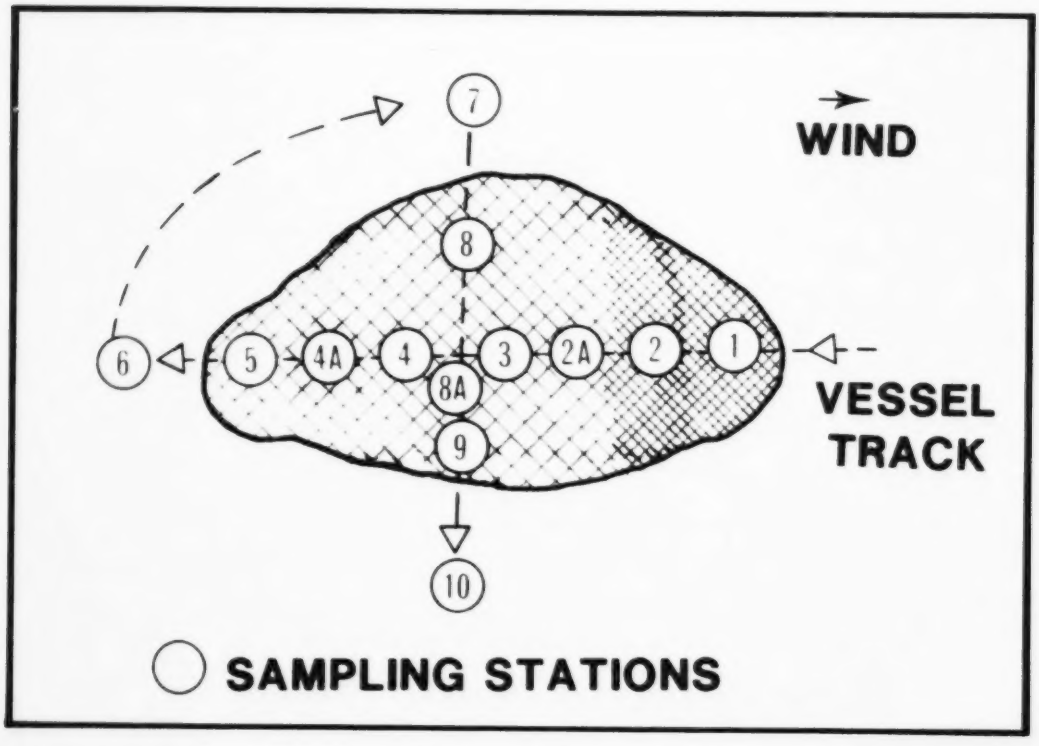


Figure 4. Schematic of Sampling Stations

TABLE 3. SAMPLING METHODS SUMMARY

Type of Sample	Locations	Preservative/ Extracting Solvent
1.5 ℓ: Extractable organics	Subsurface: all stations	50 ml CCl_4
	Surface: background and in dispersed oil	50 ml CCl_4
300 ml: low-molecular weight hydrocarbons	Surface and subsurface: "Suffix-A: stations (see Fig. 4) and background	30 mg $HgCl_2$

For the dispersed slicks, the first sampling run was started a few minutes after dispersion, and the second after about 1.3 hr. For the untreated slicks, the first run started after about 30 min, but the second run was delayed 4 to 6 hr to allow intensive sampling of the treated slicks. Times of all sampling runs are summarized in Table 4.

Samples of each crude oil were taken from the spill tank in glass bottles with teflon-lined screw caps. In the laboratory these oil samples were equilibrated with sea water collected outside the spill area, to provide equilibrium dissolved volatile hydrocarbon concentrations in sea water. These equilibrium concentrations were a basis for comparison with the test samples.

Chemical Analysis

Total extractable organic matter was measured on the single 50-ml portion of CCl_4, with an IR instrument, as absorbancy at 2930 cm^{-1}. This method measures other CCl_4 soluble compounds such as organic acids, esters, and alcohols in addition to the crude oil. These analyses were performed by Exxon Research and Engineering Co., Linden, N.J.

Volatile hydrocarbons (C_1 to C_{10} fraction) in the water samples were analyzed by a gas equilibrium method[8] at Chevron Oil Field Research Co., La Habra, CA. Forty ml of Murban and La Rosa oil samples were equilibrated with 140 ml of sea water collected before the oil spills. The oil and water were hand shaken gently and periodically for 24 hr or more. Mercuric chloride added at the time of water collection prevented possible biodegradation of dissolved hydrocarbons during equilibration and prior to analysis. This water was filtered (from one 50-ml glass syringe into a second) to remove any separate-phase oil that may have been dispersed during oil-water mixing. Twenty-five ml of this water was gas equilibrated five times.

TABLE 4. SUMMARY OF STARTING TIMES OF SAMPLING RUNS

Oil	Untreated	Treated	
	Time from Beginning of Spill	Time from End of Spraying	Time from Beginning of Spill
Murban, Complete Transects	30 min	< 15 min	< 60 min
	4.2 hr	1.1 hr	1.8 hr
		3.2 hr	3.9 hr
Single Last Station (center of slick)	6.5 hr	5.0 hr	5.7 hr
La Rosa, Complete Transects	28 min	44 min*	1.7 hr
	6.6 hr	1.5 hr	2.5 hr
		3.5 hr	4.5 hr
Single Last Station (center of slick)	8.6 hr	5.4 hr	6.4 hr

*Command aircraft could not guide ship sooner because air safety required accompanying helicopter part way back to shore.

These successive analyses were used to measure the equilibrium concentrations of individual C_1 to C_{10} hydrocarbons for the two crude oils, and to calculate individual hydrocarbon distribution coefficients.

The water samples collected at the various stations and depths were then analyzed with a single equilibration using the measured distribution coefficients to calculate concentrations. This gives sufficient accuracy and saves time and cost of multiple equilibrations. For those samples that contained significant separate phase oil, the duplicate sample was filtered and analyzed. Separate-phase oil contributes hydrocarbons to the gas phase in concentrations higher than if the hydrocarbons were only in solution. Method details are given in References 8 and 9.

SECTION 5

RESULTS AND DISCUSSION

PHYSICAL BEHAVIOR

Visual and Photographic Observations

General observations of the spills' physical behavior are discussed here in preparation for the more detailed data presentations and analyses.

Murban Spills--

These two spills appeared similar within 30 min of the beginning of oil discharge. The red-brown water-in-oil emulsion ("chocolate mousse") formed in a patch near the downwind edge of each slick, as typified by Figure 5.

After dispersant was sprayed on one slick, a very faint plume of dispersed oil was seen in the water. This plume was less visible than that from the immediately dispersed Murban spill of 1978, chiefly because the 1979 spill had spread over a much larger area, resulting in a more dilute dispersed plume. Another difference from that 1978 spill was that in 1978, surface oil was temporarily absent after spraying; in 1979, some surface oil was always visible.

In 1979, the treated spill and the control spill developed distinct differences in appearance after dispersant was applied to the test spill. For example, at 49 min after the beginning of the spill, the treated slick showed little or no mousse (Figure 6), but the untreated slick retained large mousse patches for the entire day (Figure 7). Another visible difference was the length of the two slicks at similar times after spills. The treated spill extended to 1550 m length after 3.6 hr, and a surface sheen could always be seen near a drogue set out at the time and place of spill (Figure 8). The untreated slick's length at a similar time after being spilled (3.2 hr) was 900 m (Figure 9), and the visible oil was several hundred m downwind from the drogue set out at the time and place of the spill.

La Rosa Spills--

These spills, in their first 30 minutes after discharge, both showed the usual (for La Rosa) blue-black patches of thick oil near the downwind edge (Figure 10). After dispersant application, the treated slick gradually formed into an elongated, uniform area with slightly darker regions at the upwind and downwind edges. This appearance, at 2 hr 9 min after the spill, is shown in Figure 11.

Figure 5. Murban spill that was treated, immediately before treatment (28 min. after oil was spilled).
Neg. No. 008, 009
Scale 1 cm = 14 m

Figure 6. Murban spill that was treated, 49 min. after treatment (79 min. after oil was spilled). Ship is at downwind edge of surface oil.
Neg. No. 032
Scale 1 cm = 40 m

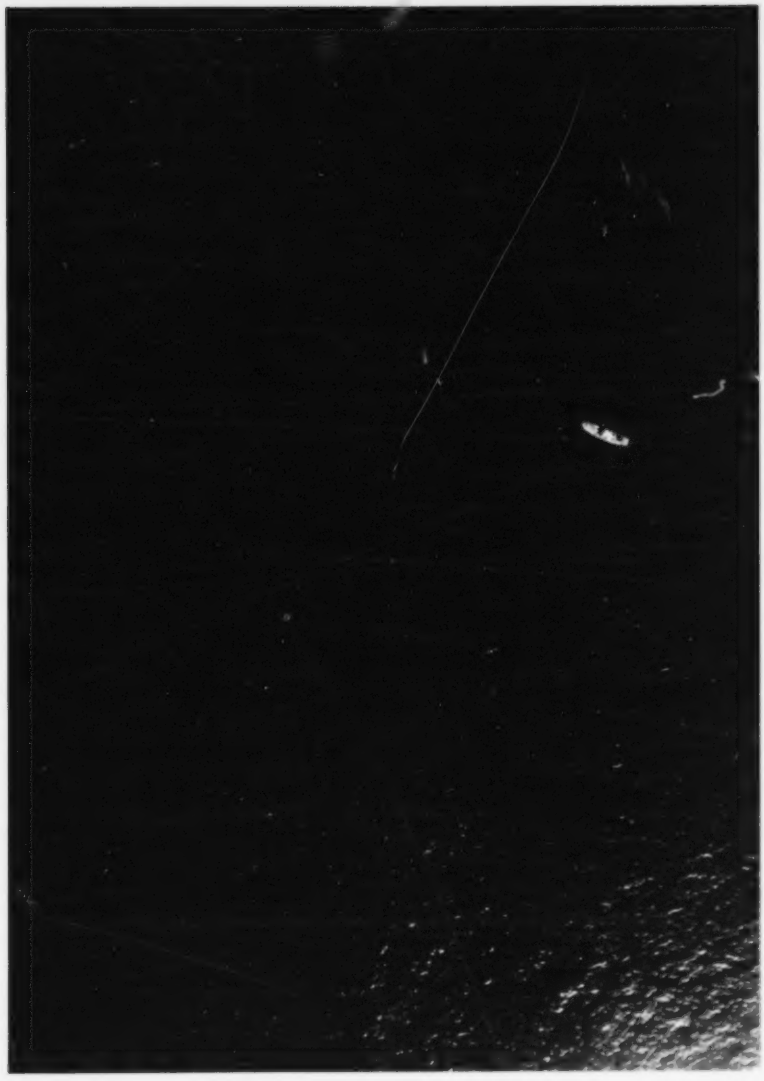


Figure 7. Untreated Murban spill, 4 hr. 54 min. after oil was spilled. Mousse is seen as faint light streaks ahead of ship.
Neg. No. 048
Scale 1 cm = 49 m

Figure 8. Treated Murban spill, 3 hr. 7 min. after treatment.
(3 hr. 37 min. after oil was spilled).
Neg. No. 050, 052, 054
Scale 1 cm = 100 m

Figure 9. Untreated Murban spill, 3 hr. 7 min. after oil was spilled.
Neg. No. 021, 022
Scale 1 cm = 33 m

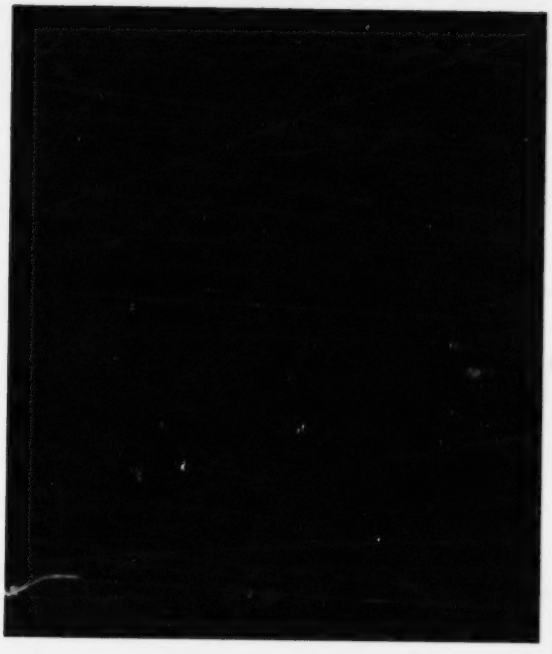


Figure 10. Untreated La Rosa spill, 15 min. after oil was spilled.
Neg. No. 087
Scale 1 cm = 34 m

Figure 11. Treated La Rosa spill, 2 hr. 9 min. after oil was spilled (1 hr. 39 min. after treatment).
Neg. No. 099, 100, 101
Scale 1 cm = 80 m

Differences between the treated spill and the control spill were similar to those observed the previous day with Murban. The treated spill was longer at any given time after spill. For example, scaling the lengths of the slicks shown in Figures 12 and 13 shows that after 5 to 6 hr, the treated La Rosa slick was about 1700 m long; the untreated slick, about 800 m. The drogue for the treated spill remained with the oil, while the control slick moved several hundred m downwind from its drogue within a few hr.

Slick Spreading

Areas of all four slicks were measured by planimeter techniques on photographs taken at various times. Results for the two Murban spills are shown in Figure 14, with 1975 and 1978 Murban data shown for comparison. Figure 15 shows similar data from the La Rosa spills of 1975, 1978, and 1979.

Several observations can be made, based on these plots and on a review of the aerial photographs. These observations emphasize the new (1979) data, because 1975/1978 interpretations have appeared in previous reports[1,6].

- After approximately 1 hr of weathering, Murban spills' rates of growth begin to differ according to time of treatment. Spills treated after 30 min or less show rapid growth in area, while spills that were not treated or were treated after 2 hr show a slower growth rate.

- La Rosa spills show trends similar to the above observations for Murban, but the groups are not so clearly defined. For La Rosa spills, the fastest growth rate was for immediate treatment (1978), followed by the treatment after 30 min (1979) and the spills that were either not treated or treated after 2 hr.

- For the duration of monitoring these spills (2 1/2 to 6 hr), the spreading rates appear independent of the amount of oil spilled (1979 volumes were more than twice those of 1978 and 1975 spills). Logic would suggest that longer monitoring durations would have revealed larger areas for spills of greater volume.

Slick Drift

Winds and currents affect the transport of oil slicks across the sea surface. The 1975 work confirmed several literature findings in that those spills moved as the vector sum of current and approximately 1% to 3% of the wind vector, and the 1979 work further substantiated these findings.

Figures 16 and 17 show the transport of surface oil, as well as wind and current vectors, for the four 1979 spills. During the time of observation for each spill, winds were fairly consistent. Currents were also fairly consistent, probably because the greater distance from shore in 1979 reduced the tidal component that caused variations in current during the 1978 tests. In reviewing Figure 17, be aware that the time for which the treated slick was observed was less than the observation time for the untreated slick. This fact, not different behavior, accounts for the appearance of a shorter travel distance for the treated slick.

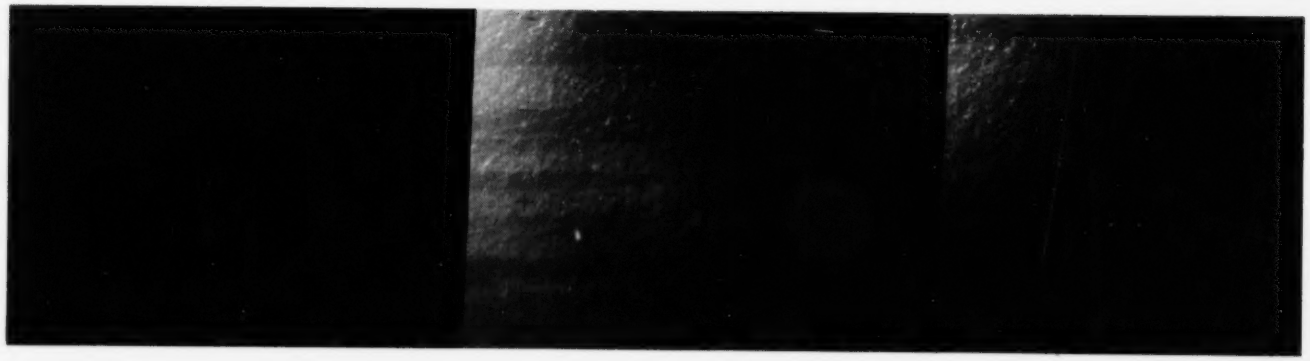


Figure 12. Treated La Rosa spill, 5 hr. 8 min. after oil was spilled (4 hr. 38 min. after treatment).
Neg. No. 127, 129, 131
Scale 1 cm = 78 m

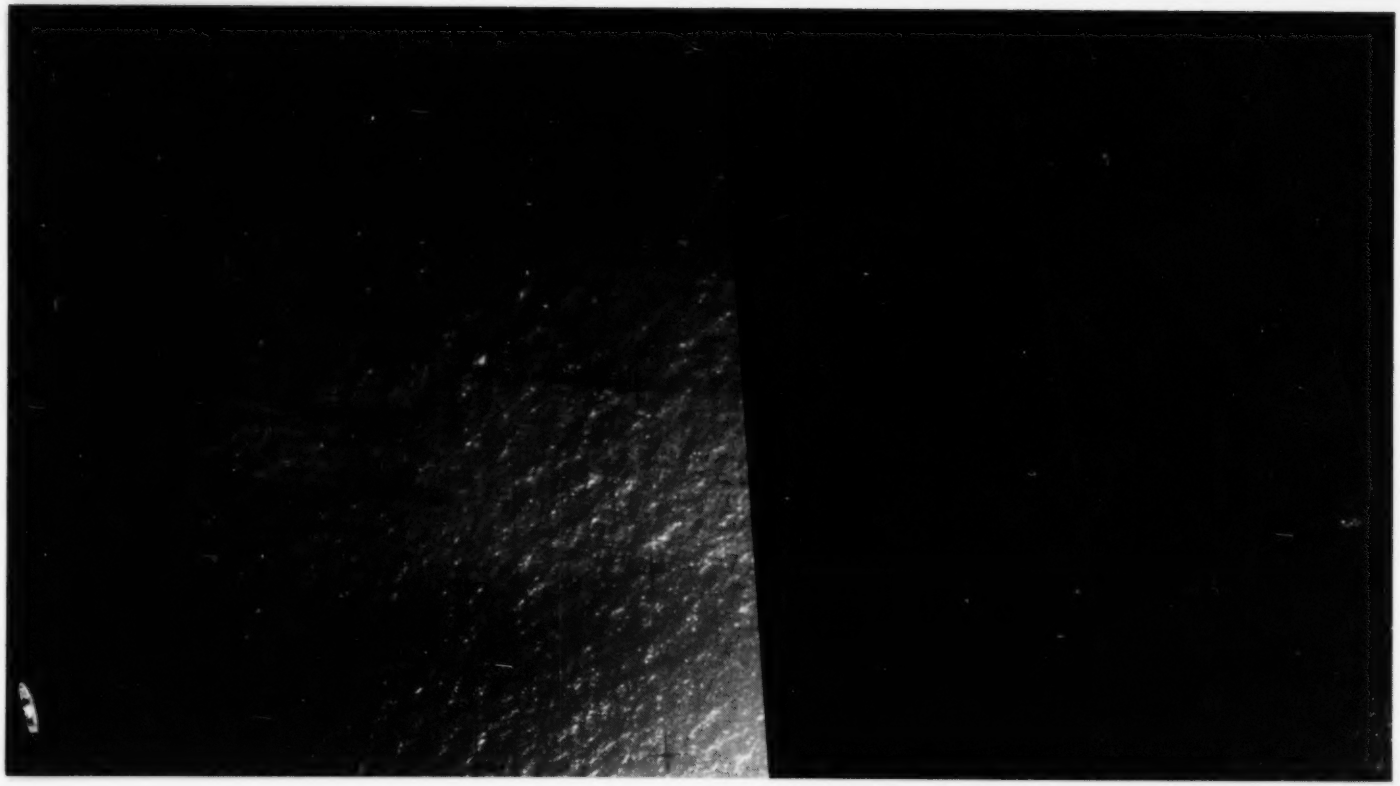


Figure 13. Untreated La Rosa spill, 6 hr. 12 min. after the oil was spilled.
Neg. No. 112, 114
Scale 1 cm = 48 m

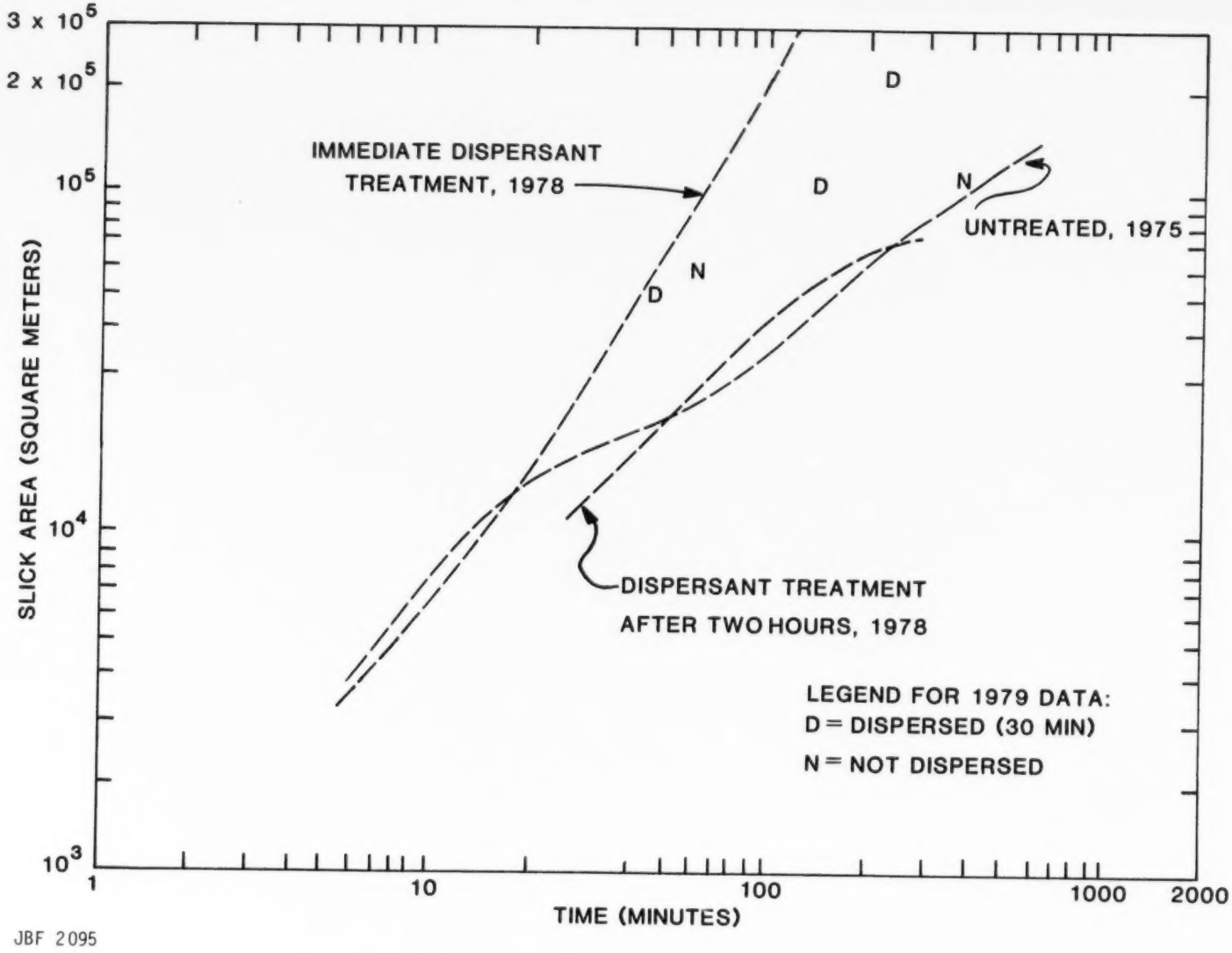
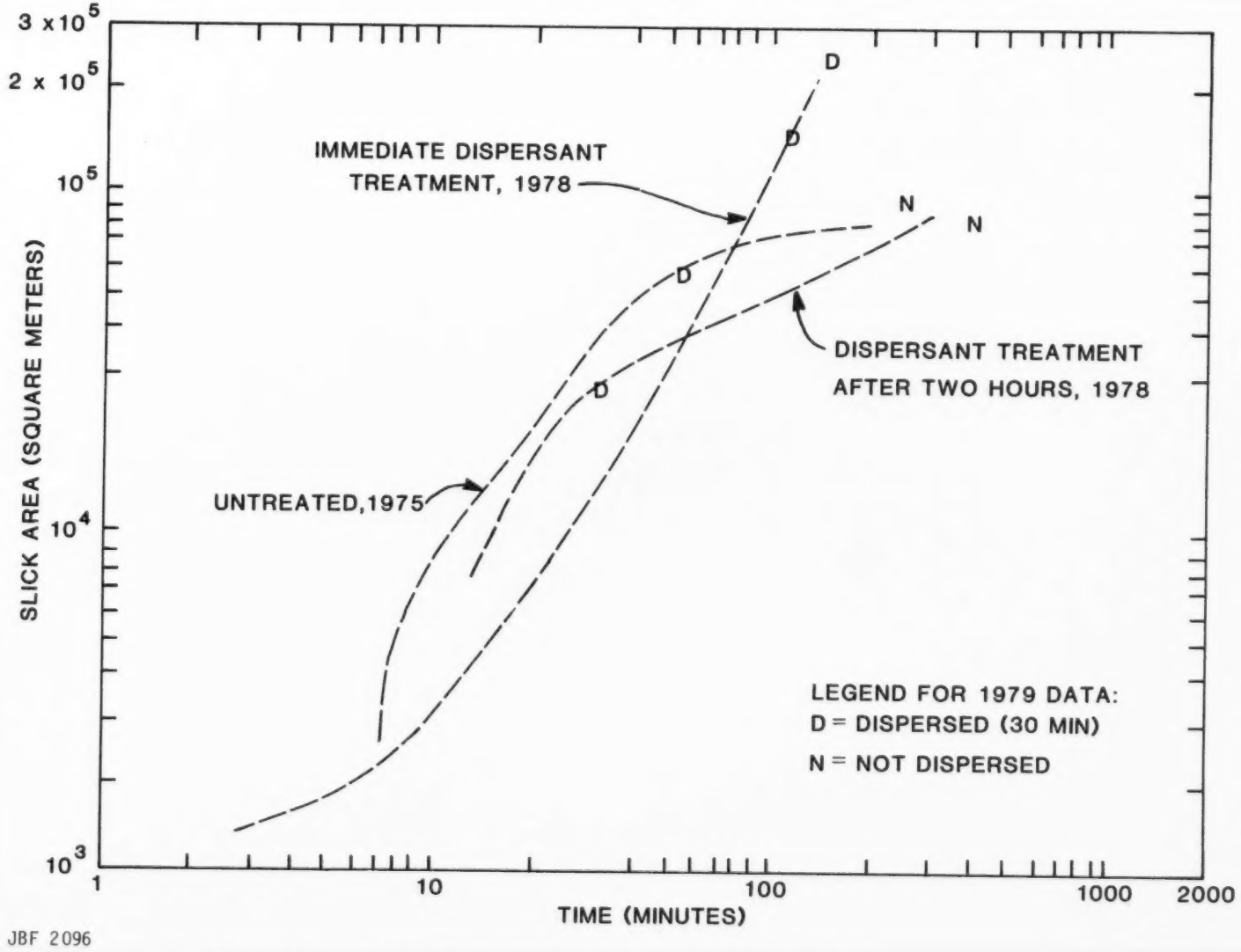


Figure 14. Slick Area Growth with Time, Murban Spills



JBF 2096

Figure 15. Slick Area Growth with Time, La Rosa Spills

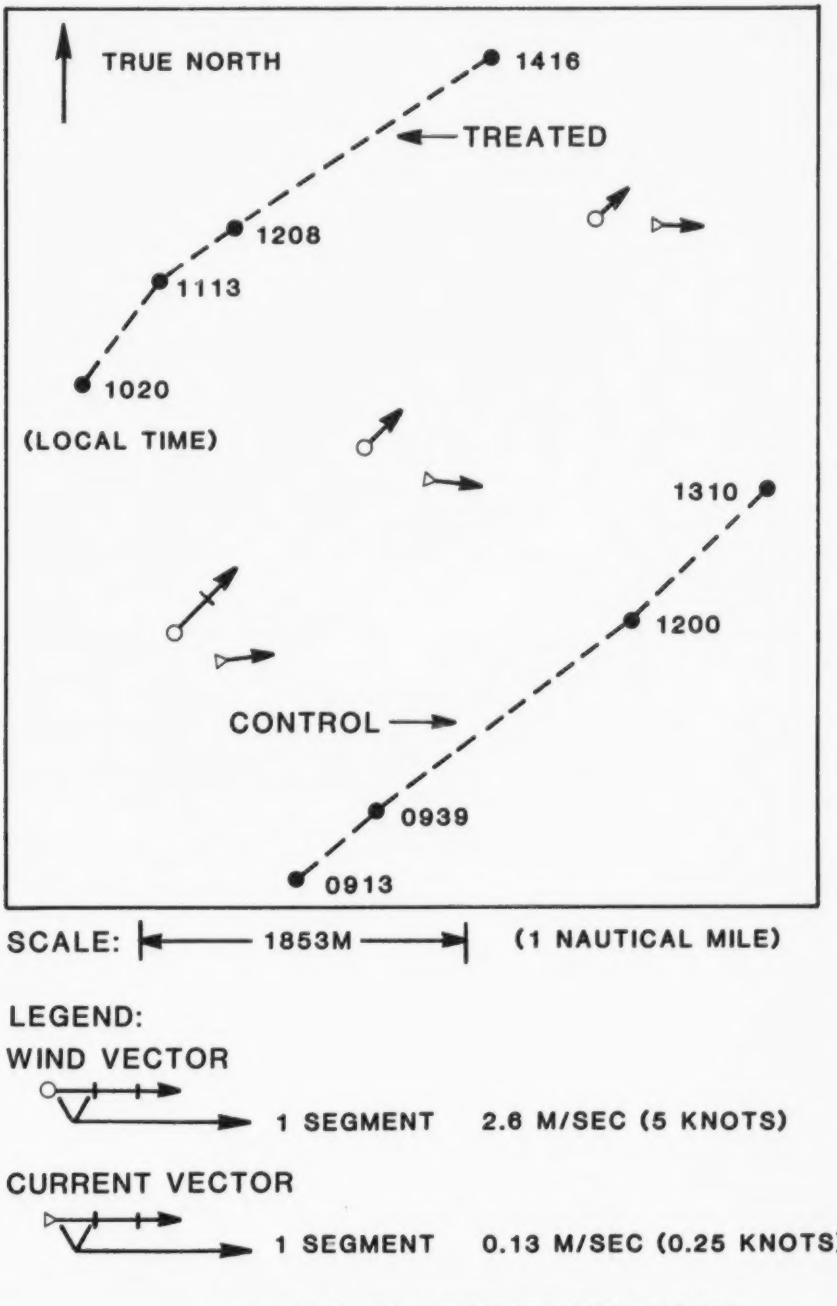


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Figure 16. Effect of wind and current on slick position: Murban spills

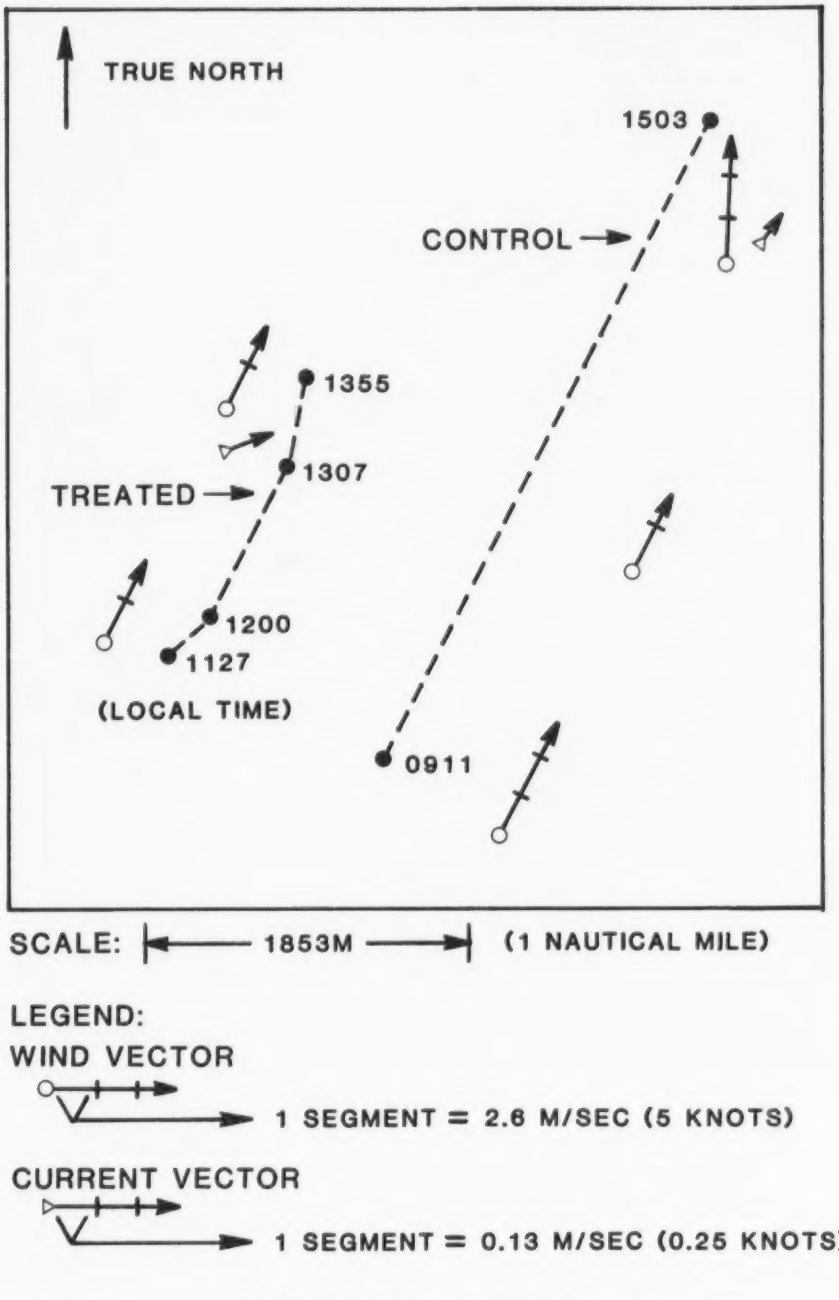

Figure 17. Effect of wind and current on slick position: La Rosa spills.

Analysis of the velocity vectors for oil, current, and wind showed results similar to those from the 1975 and 1978 tests: the effect of the wind on all surface slicks was a vector whose magnitude was approximately 3% of the wind vector. All four 1979 wind effect vectors were from 10^{0} to 30^{0} to the left of the wind vector. These effects on surface oil movement were independent of oil type or whether the oil had been treated with dispersant. The direction of movement of subsurface oil is discussed later, where the subsurface plume's fate is inferred through chemical analyses for known sample positions.

CHEMICAL ANALYSES

Analyses of the water samples provided information that complements the physical observations for overall indications of fate of the oil and some of its specific fractions.

Total Extractable Organics

Analyses of the CCl_4 extracts by infrared spectroscopy were performed by Exxon Research and Engineering Co. (ER & E). As the discussion will show, highest oil concentrations and most interesting patterns were found in the water samples from the two spills that were treated.

As a basis for comparison, analyses of background water samples taken before each spill are shown in Table 5. These data show the levels of extractable organics in the absence of a spill. Biogenic materials are the likely source of these background levels. ER & E noted that the spectra of samples containing less than about 0.09 mg/ℓ extractable organics were different from the spectra of the crude oils tested.

TABLE 5. BACKGROUND WATER ANALYSES FOR TOTAL EXTRACTABLE ORGANICS (TEO)

Date	Depth (m)	Analyses of Duplicate Samples (mg/ℓ TEO)
Oct. 22, 1979 (Murban)	0	0.046, 0.039
	1	0.077, 0.054
	3	0.040, 0.039
	6	0.035, 0.047
	9	0.034, 0.035
Oct. 23, 1979 (La Rosa)	0	0.071, 0.084
	1	0.034, 0.038
	3	0.046, 0.037
	6	0.065, 0.046
	9	0.042, 0.057
	Average	0.048
	Standard Deviation	0.015

The crossed transects of a sampling run permit a three-dimensional analysis of plumes of dispersed oil (i.e., in crossed vertical planes). In the 1978 tests, plume definition had been hindered by the small number of samples collected at 6 and 9 m depths. The 1979 program overcame this problem and, in a further attempt at better plume definition, changed the locations of the perimeter stations (1, 6, 7, and 10 in Figure 4) from well outside the visible oil to the actual edge of the oil.

Murban Spills--

Figure 18 shows the total extractable organic matter concentrations with depth along the two transects of the first sampling run following the dispersant treatment of Murban crude oil. The vertical scale exaggeration is about 45 X. The contour for 0.25 mg/ℓ was at approximately 5 m at its deepest point; for the 1.0 mg/ℓ contour, approximately 4 m.

The second set of transects through this spill, with each station occupied about 1 hr after the corresponding station from the first set of transects, is represented by Figure 19. Dilution with time between these sample sets had reduced concentrations; all subsurface samples were less than 1 mg/ℓ.

The highest oil concentrations from both of these sample sets were at two locations: the upwind and downwind limits of the visible oil. The immediately treated spills in 1978 did not show such multiple zones of high oil concentrations. Several hypothetical mechanisms in the 1979 tests could produce this effect, singly or in combination:

- The helicopter spray may have been uneven.
- The upwind plume may have been dispersed naturally before treatment, while the downwind plume was caused by the spray on the heavy oil that was moved downwind before treatment.
- The upwind slick area, although it contained less oil than the downwind area, may have contained fractions that were more responsive to the dispersant.
- The upwind plume contained oil that was dispersed at the time of spraying, while the downwind plume was caused by delayed action of the dispersant. That is, the surface oil at the downwind end of the slick was continuing to disperse because of the presence of the dispersant.

The first of these hypotheses is unlikely, because (as the discussion of the La Rosa spills will show) similar behavior was found for the dispersed La Rosa spill. In addition, tests off the California coast during 1978 and 1979 using fixed-wing spray planes and dispersant application by boat found similar patterns, where the upwind and downwind areas showed higher oil concentrations than the center of the slick area[5].

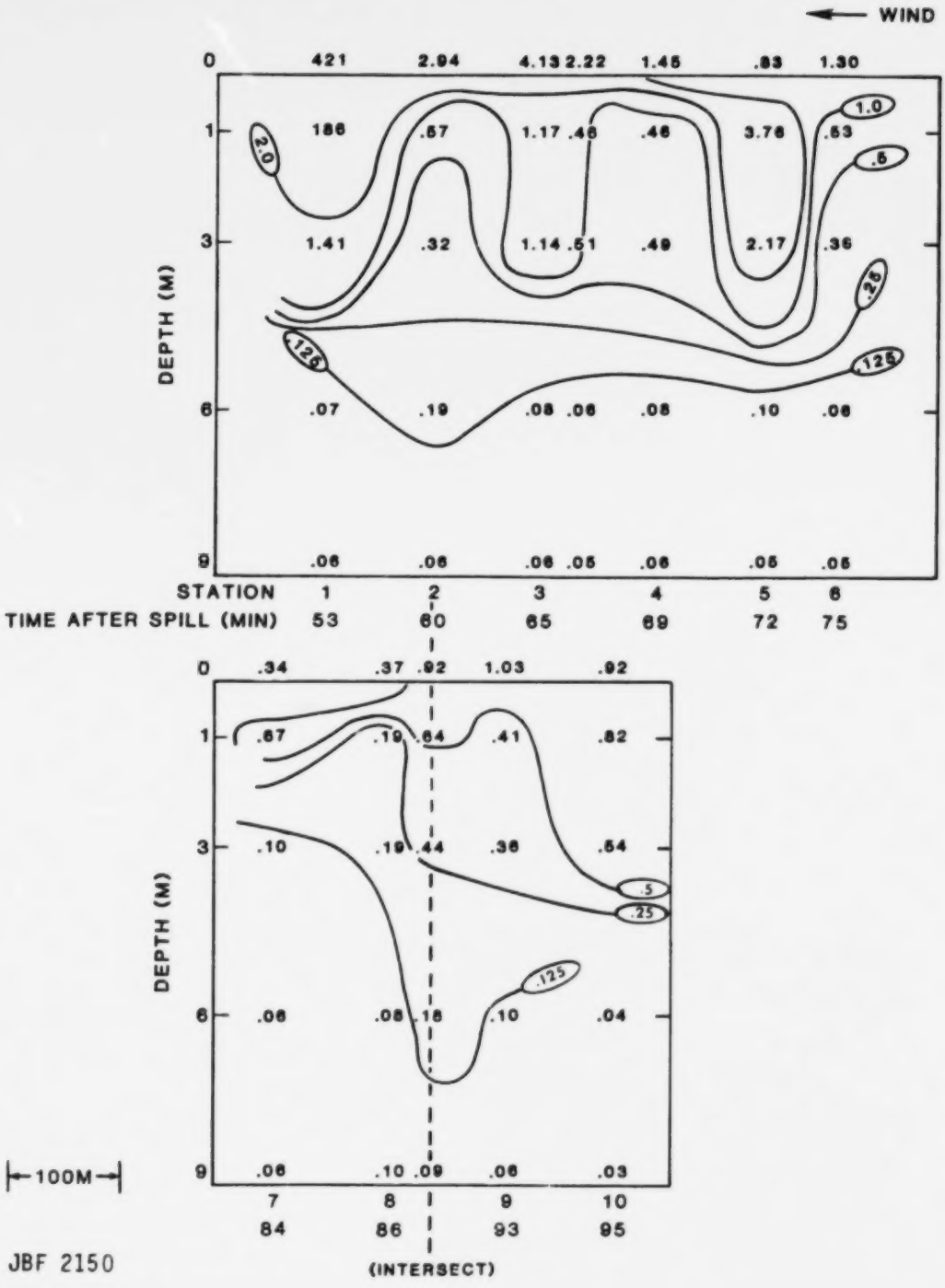

Figure 18. Total extractable organic matter (mg/l) in water samples collected during first sample run through treated Murban crude oil spill. Vertical exaggeration about 45 X.

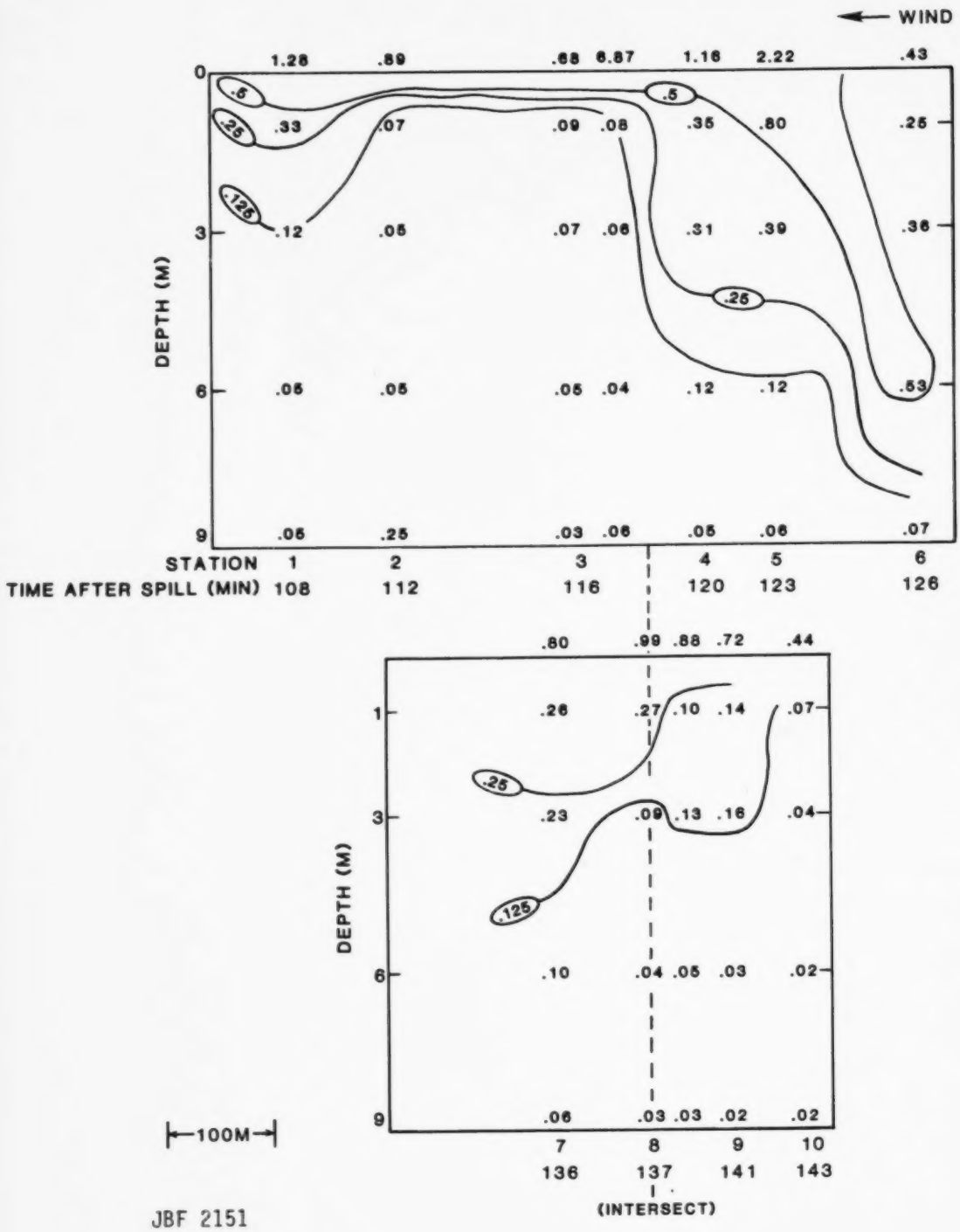

Figure 19. Total extractable organic matter (mg/ℓ) in water samples collected during second sample run through treated Murban crude oil spill. Vertical exaggeration about 45 X.

Rigorously separating the possible contributions of the other three hypothetical mechanisms is not possible with the data available. One piece of evidence supporting the second listed hypothesis (some natural dispersion before treatment) is available, however. At station 9 in the control spill at 61 minutes after the spill, the following concentrations were found at 1, 3, 6, and 9 m depth: 2.8, 1.96, 4.6, and 0.65 mg/ℓ. Figure 20 shows concentration contours for this sample set. Although the high concentration area is small, the two transects are consistent in their indication of oil concentrations well above background in the vicinity of stations 4, 5, and 9, near the upwind edge of the slick. The concentrations and depths are similar to those shown for the upwind plume area in Figure 18, suggesting that the upwind plume in the treated spill may be at least partly caused by natural dispersion before dispersant application. One complicating factor here, in the first spill, is that the Cape Henlopen was having difficulty maintaining station; the high values may have been caused by excessive propeller action.

Quality control (QC) samples were taken under the dispersed Murban spills on each transect after stations 3 and 8. These were not rigorous duplicates because they differed in time (1-2 min) and space (30-60 m) from the station 3 or 8 samples. The analyses for these QC samples are shown on Figures 18 and 19, as the values between Stations 3 and 4, and Stations 8 and 9. They confirm the validity of the data upon which the concentration contours are based.

The movement of perimeter stations to the edge of the visible oil often caused poor resolution of plume boundaries. Figures 16 and 17 show that all stations were inside the plume (well above background). The 1978 work, however, showed that the plumes did not extend beyond the visible oil perimeter more than about 20-40 m. Therefore, it is probably valid to assume that the perimeter stations in 1979 were within this distance of the edges of the dispersed oil plume.

La Rosa Spills--

Figure 21 shows the extractable organic matter concentrations for the treated La Rosa spill for the first sampling run, in a similar manner to the plot of Figure 18 for Murban. The maximum penetrations for concentrations of 0.25 through 2 mg/ℓ were all between 6 and 9 m depth. The 4 mg/ℓ contour was between 3 and 6 m deep. The penetrations of the concentrations contours are somewhat deeper than those for Murban at the upwind end, but not so deep at the downwind end of the spill area. The finding of highest oil concentrations at the upwind and downwind ends of this slick concurs with the visual observations discussed earlier. A few samples shown in Figure 21 have spuriously low values. These are primarily the quality control samples taken between stations 8 and 9. At this time, aerial photographs show the Albert and the Cape Henlopen to have been quite close to each other. These samples may therefore represent some clean water pumped into the plume by the Cape Henlopen's propellers. All other sets of QC samples for this spill lend credence to the results. The very low value for the 1-m sample at station 7 represents a 1.5-ℓ bottle that was found to contain only CCl_4, unlike all other samples that were brought to shore containing both CCl_4 and water phases. The reason for this anomaly is unknown, but the value should be disregarded.

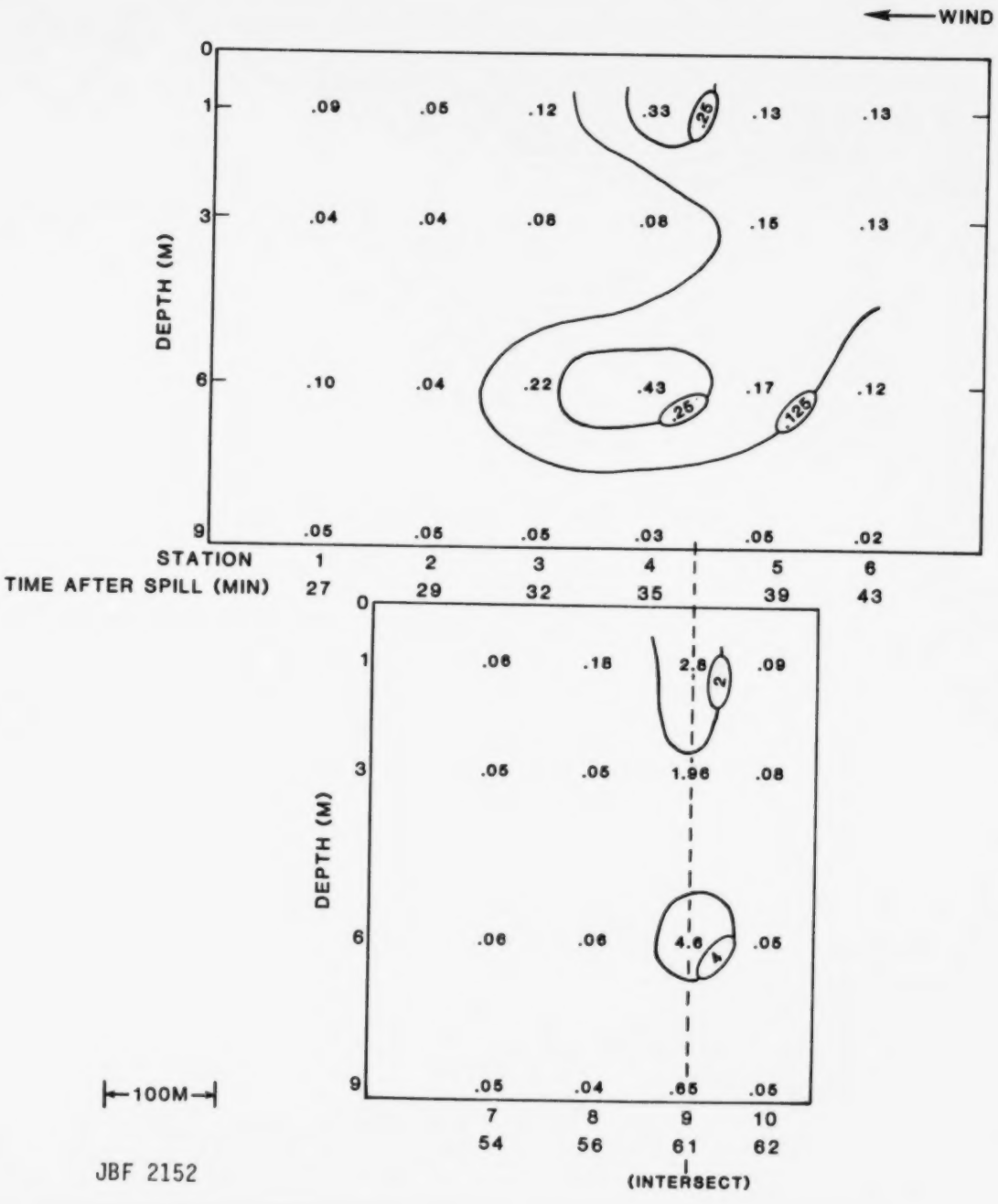

Figure 20. Total extractable organic matter (mg/ℓ) in water samples collected during first sample run through untreated Murban crude oil spill. Vertical exaggeration about 45 X.

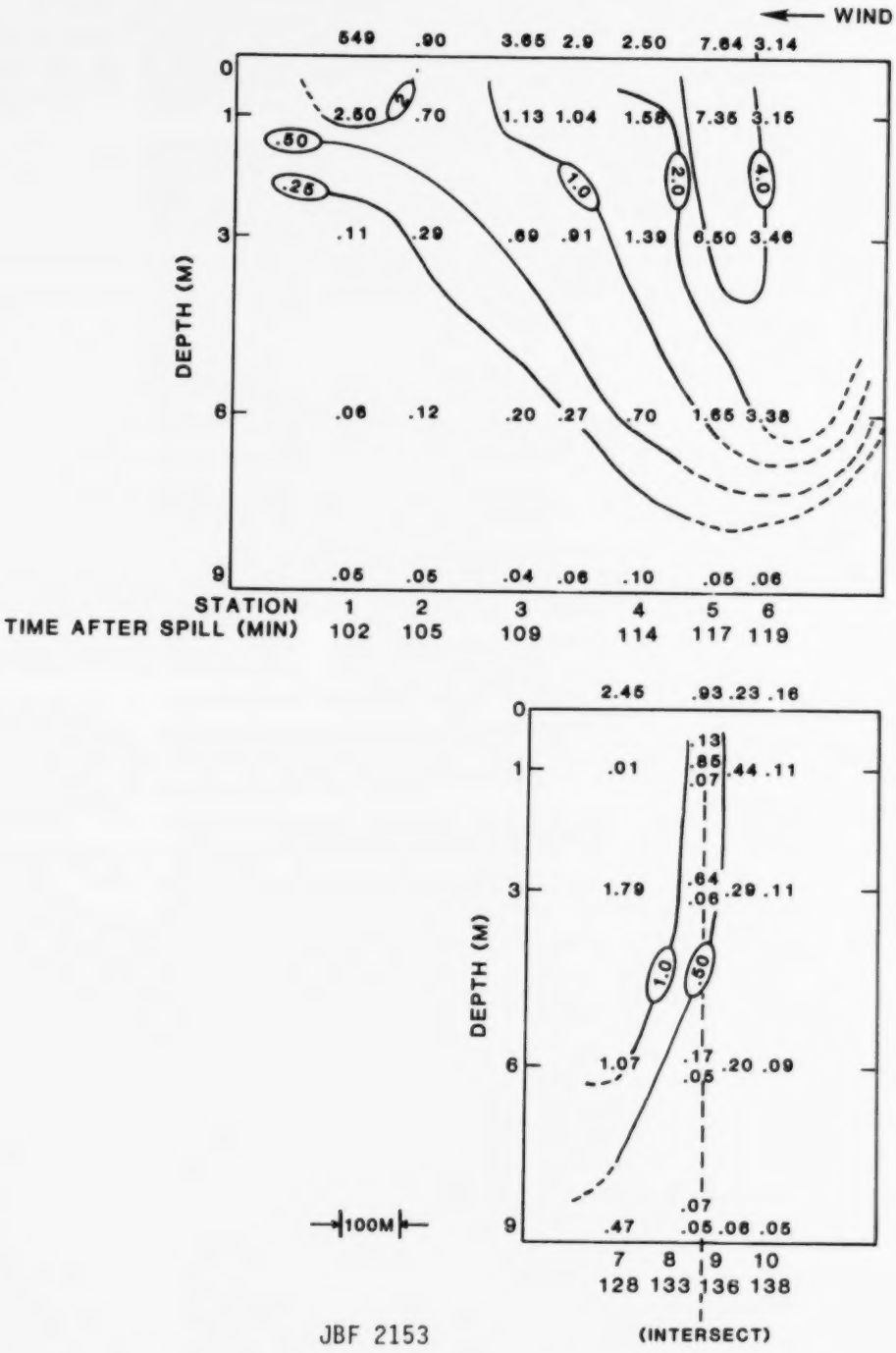

Figure 21. Total extractable organic matter (mg/ℓ) in water samples collected during first sample run through treated La Rosa crude oil spill. Vertical exaggeration about 45 X.

Results of the second sampling run for this spill are depicted in Figure 22. The areas of relatively high oil concentrations upwind and downwind are evident, as is the fact that the crosswind transect passed between these two areas.

Of the samples from under the untreated La Rosa spill, only two contained extractable organics in excess of 0.3 mg/ℓ. A value of 2.1 mg/ℓ was found at the 1-m sample, station 2, first transect. Concentrations between 0.1 and 0.2 mg/ℓ were found in 16 of the 40 samples taken on this set of transects (Figure 23).

Sampling runs performed more than 4 hr after each spill revealed much lower concentrations than the sampling runs discussed here. Data from the later runs are presented in Appendix A.

Comparisons Among Tests--

For each crude oil tested, the difference in oil concentrations between treated and untreated spills is dramatic. To quantitate these differences, mass balance computations were performed. The results of these computations allow comparison between crudes as well as between treated and untreated behavior of each crude.

Because of the irregular shapes of the concentration contours, simple geometric shapes could not be assumed as they were in analyzing the 1978 data. (The analysis of 1978 data assumed pyramid shapes for contours.) In addition, the poor definition of the edges of plumes in the 1979 data required assumptions and estimates about the shape of contour lines returning to the sea surface at the plume edges. Specifically, it was assumed that all concentration contours met the sea surface 50 m outside the edge of the visible oil.

Amounts of oil in the water were computed, using the following procedure.

- For Figures 18 through 23, the area bounded by the concentration contours, or isopleths, in the longer transect was measured with a planimeter. Because the crosswind transects often missed the areas of highest oil concentration, it was assumed that the crosswind plume shape at all points was an inverted triangle whose nadir was the isopleth in the logitudinal direction. The volume bounded by each isopleth was therefore computed by multiplying the measured logitudinal plane area by one-half the average width of the visible oil.

- The amount of extractable organic matter within each volume was determined by multiplying the volume by the concentration, with appropriate dimensional conversions.

- Double accounting was avoided by using the incremental volumes and concentrations between isopleths, and summing the results.

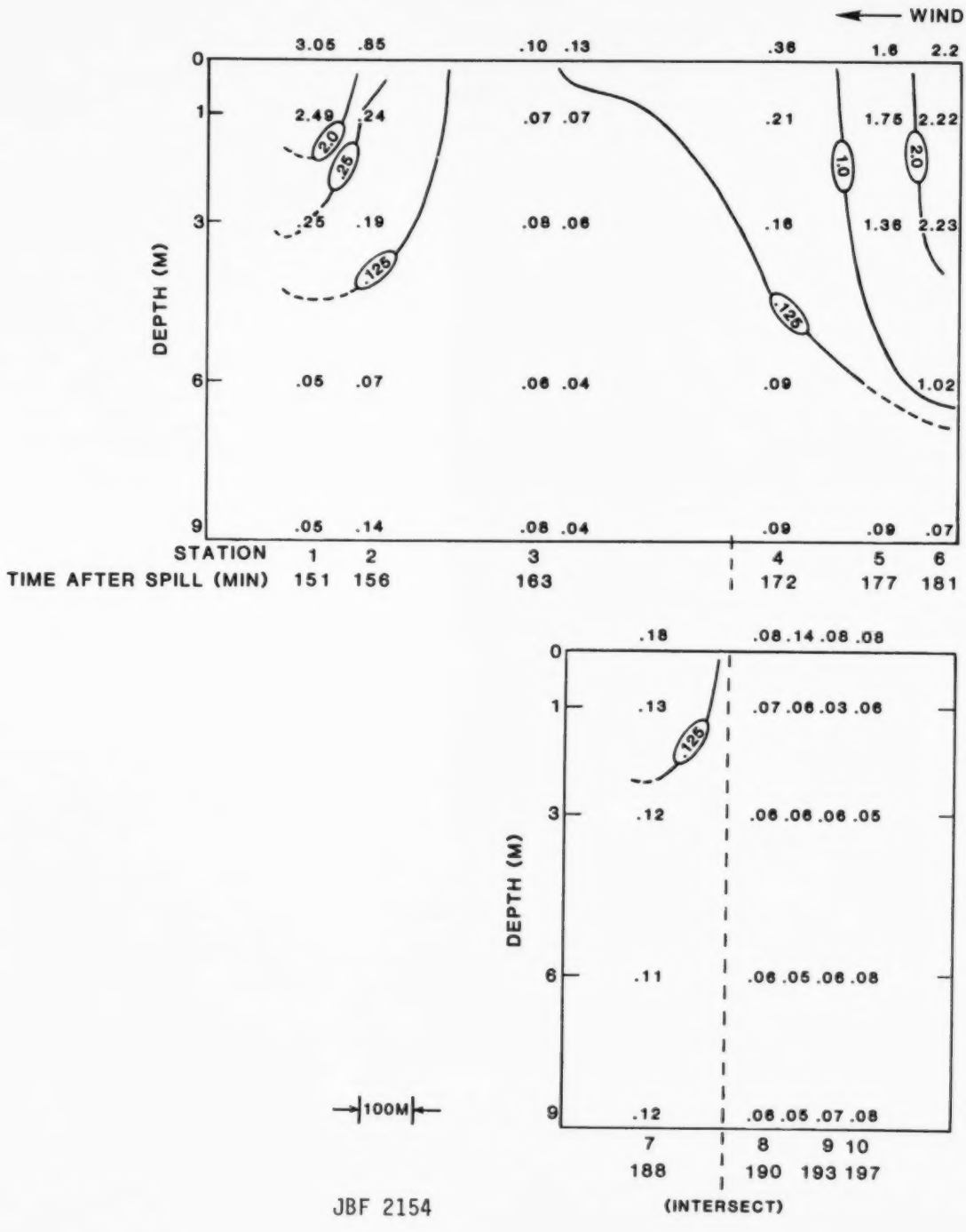

Figure 22. Total extractable organic matter (mg/ℓ) in water samples collected during second sample run through treated La Rosa crude oil spill. Vertical exaggeration about 45 X.

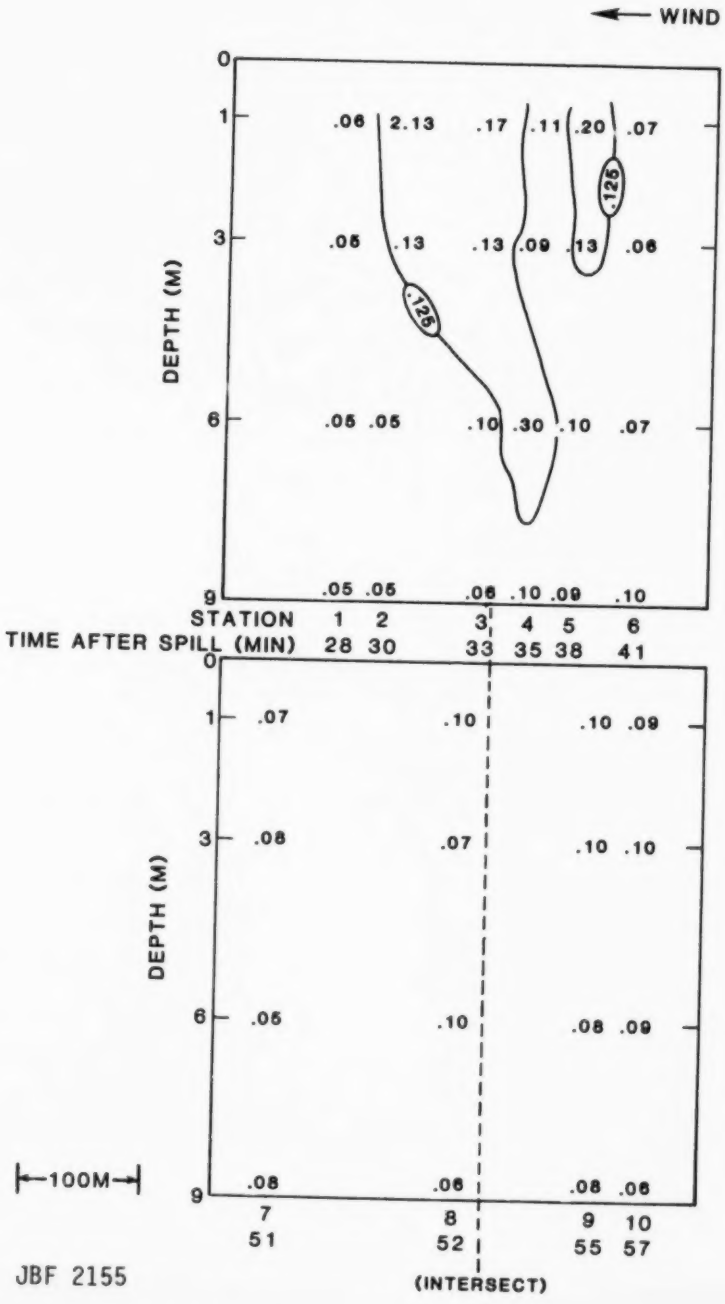

Figure 23. Total extractable organic matter (mg/ℓ) in water samples collected during first sample run through untreated La Rosa crude oil spill. Vertical exaggeration about 45 X.

The results should be used with great caution as to absolute quantities of oil in the water but the relative amounts for different oils and treatments should be useful for comparisons because all computations used the same assumptions. The reasons for the approximate nature of the absolute oil quantities include:

- The isopleths represent changes in time as well as position. Only the vertical samples at a given station were simultaneous. Stations were occupied sequentially.
- The approach to computing volumes within each isopleth was very approximate, especially for the assumption of a triangular cross-wind plume shape. Another critical assumption was that the isopleth described by the logitudinal transect represents the most concentrated part of the plume.

Results are shown in Table 6.

TABLE 6. APPROXIMATE PERCENT OF SPILLED OIL ACCOUNTED FOR IN WATER SAMPLES

Crude Oil Type	Condition		
	Treated		Control
	1st Transect	2nd Transect	
Murban	50-90**	6***	< 5*
La Rosa	60***	2****	< 1*

*25 to 60 min after spill.
**50 to 100 min after spill.
***100 to 150 min after spill.
****151 to 197 min after spill.

Table 6 yields several interesting observations and comments:

- The first sampling run through treated Murban crude gives a range of reasonable results based on the average concentration used for the volume within the 2 mg/ℓ isopleth (Figure 18). An average concentration of 18.3 mg/ℓ would account for all the oil; an average of 14.2 mg/ℓ would account for 50% of the oil.
- Even though the first transect through treated La Rosa was about 50 min later than the first transect through treated Murban, approximately the same amount of oil was found.

- Comparing the first transect through treated La Rosa with the second transect through treated Murban (samples at similar times), much more oil was found in the La Rosa plume. This observation may be caused by more evaporation from the Murban plume, less accurate sampling locations for the Murban plume, or more lateral dispersion of the Murban plume. This last factor would result from the fact that any second run through a plume, regardless of plume age, attempts to define a plume that has been subjected to much propeller action from the two ships. This propeller wash could have swept dispersed oil away from the main visible mass of oil being sampled. The most likely cause for finding less oil on the second transect is this difficulty in sampling enough stations over a large enough area.

In addition, it should be noted that the percentage dispersion found in the first transects compares roughly with that found after immediate treatment of these oils in 1978. Therefore, weathering within the first 30 min appears not to affect these oils' capability to be dispersed.

Summary--A summary of the total extractable organic matter in water under the four research spills is shown in Table 7. It includes only values exceeding 0.10 mg/ℓ (approximately two times background). Untreated oil dispersed naturally in the water to a lesser extent than chemically treated oil, as preceding discussons have shown.

Comparing the data in Table 7 for the two dispersed spills shows a trend for La Rosa to have higher oil concentrations at the 3, 6, and 9 m depths, while Murban in the first sampling run showed higher concentrations at 1 m than La Rosa. This apparent difference may be caused by the greater buoyancy of Murban crude.

Low-Molecular-Weight Hydrocarbons

One hundred and four samples for GC analysis were collected at "suffix A" stations (Figure 4). Of these, 58 were selected for analysis based on a likelihood of finding hydrocarbons, as suggested by the previous IR analysis for total oil. Of these 58 samples, 23 were found to have concentrations above background. These data, as well as those from the biology ship's samples, are listed in Appendix B.

The small number of samples with concentrations above background results partly from the weathering of these spills before treatment; low-molecular-weight hydrocarbons that might have been dispersed were allowed to evaporate for 30 min before dispersant treatment.

In an attempt to interpret these limited data, Table 8 has been prepared. The table classifies the GC samples according to the amounts of total oil found by IR in samples taken nearby in time and space. As the table shows, the three samples with the highest TEO values also showed elevated concentrations of C_1 - C_{10} hydrocarbons. In waters containing less than 1 mg/ℓ TEO, no trends were apparent.

TABLE 7. SUMMARY OF CARBON TETRACHLORIDE EXTRACTABLE ORGANIC MATTER IN WATER FROM UNDER FOUR RESEARCH OIL SPILLS (mg/ℓ)

Oil Condition	Sample Depth (m)	Sample Run No.	Murban			La Rosa		
			N**	Maximum	Mean	N**	Maximum	Mean
Not Dispersed	1	1	6	2.8	0.61	6	2.1	0.47
		2	2	0.16	0.14	3	0.12	0.11
	3	1	3	2.0	0.75	5	0.13	0.12
		2	0	-	-	3	0.15	0.13
	6	1	6	4.6	0.94	4	0.30	0.15
		2	1	0.10	0.10	0	-	-
	9	1	1	0.65	0.65	2	0.10	0.10
		2	0	-	-	0	-	-
Dispersed at 30 min	1	1	12	186	16.3	10	7.35	1.88
		2	8	0.80	0.31	6	2.49	1.17
		3	8	0.35	0.16	7	1.05	0.47
	3	1	12	2.2	0.67	11	6.50	1.47
		2	7	0.39	0.24	6	2.23	0.72
		3	5	0.28	0.17	6	0.46	0.25
	6	1	4	0.19	0.14	9	3.38	0.86
		2	4	0.53	0.22	2	1.02	0.57
		3	1	0.10	0.10	3	0.36	0.23
	9	1	1	0.10	0.10	3	0.47	0.23
		2	1	0.25	0.25	2	0.14	0.13
		3	0	-	-	1	0.11	0.11

*Average background concentrations (mg/ℓ): 1 m, 0.050; 3 m, 0.041; 6 m, 0.048; 9 m, 0.042. Four background samples at each depth.

**Number of samples $\geq$ 0.10 mg/ℓ.

TABLE 8. SUMMARY OF LOW-MOLECULAR-WEIGHT HYDROCARBON CONCENTRATIONS

Approximate Total Extractable Organics (mg/ℓ) (Based on isopleths, Figs. 16 through 21)	Number of Samples Analyzed by GC	Total C_1 - C_{10} Hydrocarbons (µg/ℓ)	
		Range	Mean
>1.0	3 (All Treated)	1.89-5.73	3.4
0.7-0.9	4 (All Treated)	b*-1.75	1.2
0.2-0.5	6 (Treated)	b-2.57	1.5
	1 (Untreated)	1.64	1.6
<0.2	15 (Treated)	b	b
	9 (Untreated)	b-3.85	1.6

*b = background (approximately 1 µg/ℓ).

It should be noted, however, that samples from under control slicks, while generally low in TEO, showed relatively high levels of C_1 - C_{10} hydrocarbons. Implications of this observation are uncertain, because these samples were closer to the time of spill than the samples from treated spills shown in Table 8 (by about 30 min). If the time factor is not important, the data may suggest that oil in the water under untreated spills contains a higher percentage of volatiles than the oil in water samples from dispersed spills. In other words, dispersants may enhance evaporation of low-molecular-weight hydrocarbons from crude oil slicks.

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APPENDIX A

Listing of data from Exxon Research & Engineering Company that are not presented in the body of this Report.

Crude	Condition	Sample	Station	Time After Spill	Extractable Organics in Water (mg/l) 0m	1m	3m	6m	9m
Murban	Not Treated	171	1	4:25		0.16			
		172	1	"			0.05		
		173	1	"				0.04	
		174	2	4:27		0.07			
		175	2	"			0.05		
		176	2	"				0.05	
		177	3	4:31		0.06			
		178	3	"			0.05		
		179	3	"				0.05	
		180	4	4:36		0.05			
		181	4	"			0.06		
		182	4	"				0.10	
		183	5	4:40		0.07			
		184	5	"			0.06		
		185	5	"				0.05	
		186	6	4:41		0.09			
		187	6	"			0.09		
		188	6	"				0.06	
		189	7	4:54		0.12			
		190	7	"			0.09		
		191	7	"				0.06	
		192	7	"					0.04
		193	8	4:55		0.06			
		194	8	"			0.05		
		195	8	"				0.04	
		196	8	"					0.03
		197	9	4:58		0.06			
		198	9	"			0.05		
		199	9	"				0.04	
		200	9	"					0.07
		201	10	5:00		0.06			
		202	10	"			0.05		
		203	10	"				0.04	
		204	10	"					0.05
		260	Center	6:42		0.10			
		261	"	"			0.09		
		262	"	"				0.07	
		263	"	"					0.06
Murban	Treated	205	1	3:56	31.2				
		206	1	"		0.11			
		207	1	"			0.05		
		208	1	"				0.09	
		209	1	"					0.05

Crude	Condition	Sample	Station	Time After Spill	Extractable Organics in Water (mg/l) 0m	1m	3m	6m	9m
Murban	Treated	210	2	4:00	0.97				
		211	2	"		0.07			
		212	2	"			0.07		
		213	2	"				0.06	
		214	2	"					0.04
		215	3	4:09	0.30				
		216	3	"		0.06			
		217	3	"			0.06		
		218	3	"				0.06	
		219	3	"					0.05
		220	4	4:16	0.23				
		221	4	"		0.10			
		222	4	"			0.05		
		223	4	"				0.05	
		224	4	"					0.05
		225	5	4:25	0.59				
		226	5	"		0.23			
		227	5	"			0.18		
		228	5	"				0.06	
		229	5	"					0.06
		230	6	4:29	0.51				
		231	6	"		0.35			
		232	6	"			0.28		
		233	6	"				0.07	
		234	6	"					0.06
		235	7	4:35	0.21				
		236	7	"		0.15			
		237	7	"			0.11		
		238	7	"				0.10	
		239	7	"					0.07
		240	8	4:37	0.25				
		241	8	"		0.15			
		242	8	"			0.12		
		243	8	"				0.06	
		244	8	"					0.07
		245	8	"	0.15				
		246	8	"		0.08			
		247	8	"			0.07		
		248	8	"				0.05	
		249	8	"					0.07
		250	9	4:40	0.25				
		251	9	"		0.10			
		252	9	"			0.15		

Crude	Condition	Sample	Station	Time After Spill	Extractable Organics in Water (mg/l) 0m	1m	3m	6m	9m
Murban	Treated	253	9	4:40				0.05	
		254	9	"					0.06
		255	10	4:45	0.17				
		256	10	"		0.10			
		257	10	"			0.07		
		258	10	"				0.07	
		259	10	"					0.05
		264	Center	5:42	0.20				
		265	"	"		0.14			
		266	"	"			0.08		
		267	"	"				0.22	
		268	"	"					0.06
La Rosa	Not Treated	439	1	6:21		0.08			
		440	1	"			0.12		
		441	1	"				0.07	
		442	1	"					0.08
		443	2	6:24		0.12			
		444	2	"			0.07		
		445	2	"				0.08	
		446	2	"					0.05
		447	3	6:29		0.09			
		448	3	"			0.09		
		449	3	"				0.06	
		450	3	"					0.07
		451	4	6:31		0.06			
		452	4	"			0.08		
		453	4	"				0.07	
		454	4	"					0.05
		455	5	6:33		0.11			
		456	5	"			0.12		
		457	5	"				0.06	
		458	5	"					0.05
		459	6	6:36		0.06			
		460	6	"			0.15		
		461	6	"				0.06	
		462	6	"					0.05
		463	7	6:49		0.11			
		464	7	"			0.07		
		465	7	"				0.04	
		466	7	"					0.05
		467	8	6:52		0.07			
		468	8	"			0.07		

Crude	Condition	Sample	Station	Time After Spill	Extractable Organics in Water (mg/l) 0m	1m	3m	6m	9m
La Rosa	Not Treated	469	8	6:52				0.07	
		470	8	"					0.05
		471	9	6:55		0.07			
		472	9	"			0.07		
		473	9	"				0.07	
		474	9	"					0.06
		475	10	6:58		0.05			
		476	10	"			0.06		
		477	10	"				0.05	
		478	10	"					0.03
		530	Center	8:35		0.09			
		531	"	"			0.10		
		532	"	"				0.08	
		533	"	"					0.06
La Rosa	Treated	479	1*	4:33	4.15				
		480	1	"		0.17			
		481	1	"			0.08		
		482	1	"				0.07	
		483	1	"					0.07
		484	2*	4:43	1.8				
		485	2	"		1.1			
		486	2	"			0.22		
		487	2	"				0.09	
		488	2	"					0.06
		489	3*	4:50	0.31				
		490	3	"		0.27			
		491	3	"			0.16		
		492	3	"				0.07	
		493	3	"					0.08
		494	4*	4:59	0.24				
		495	4	"		0.06			
		496	4	"			0.10		
		497	4	"				0.06	
		498	4	"					0.07
		499	5*	5:07	0.26				
		500	5	"		0.07			
		501	5	"			0.06		
		502	5	"				0.05	
		503	5	"					0.05
		504	6*	5:10	0.21				
		505	6	"		0.39			
		506	6	"			0.07		

Crude	Condition	Sample	Station	Time After Spill	Extractable Organics in Water (mg/l) 0m	1m	3m	6m	9m
La Rosa	Treated	507	6	5:10				0.06	
		508	6	"					0.06
		509	7*	5:13	0.14				
		510	7	"		0.05			
		511	7	"			0.09		
		512	7	"				0.06	
		513	7	"					0.05
		514	8*	5:15	0.55				
		515	8	"		0.46			
		516	8	"			0.34		
		517	8	"				0.14	
		518	8	"					0.11
		519	9*	5:18	0.09				
		520	9	"		0.47			
		521	9	"			0.46		
		522	9	"				0.36	
		523	9	"					0.08
		525	10*	5:20	0.53				
		526	10	"		0.48			
		527	10	"			0.18		
		528	10	"				0.19	
		529	10	"					0.05
		538	Center	6:23	0.21				
		534	"	"		0.12			
		535	"	"			0.06		
		536	"	"				0.06	
		537	"	"					0.05

*All 10 stations in this series were on a single transect through the long dimension of the slick (parallel to the wind).

APPENDIX B

DATA FROM CHEVRON OIL FIELD RESEARCH CO.

Chevron Oil Field Research Company
A Standard Oil Company of California Subsidiary
P.O. Box 446, La Habra, CA 90631, U.S.A.

November 3, 1980

Mr. Jaret C. Johnson
JBF Scientific Corporation
2 Jewel Drive
Wilmington, MA 01887

Dear Jay:

Enclosed are four tables that summarize the C_1 to C_{10} volatile hydrocarbons measured in samples collected during the 1979 East Coast research oil spills.

Table 1 shows the background concentrations (µg/L, ppb) measured in samples prior to the oil discharges. These very low concentrations of aromatic hydrocarbons may be in seawater, or from the pumping system (polypropylene tubing), seals on bottles or laboratory contamination. In any event, they are quite low. Only 12 of the samples analyzed (Tables 1 and 3) show concentrations of C_1 to C_{10} hydrocarbons that are higher than background (background has not been subtracted). None of these samples contained very high concentrations of dispersed oil as shown by the values at the bottom of Table 1. It is unfortunate that samples were not collected during the first sample run following dispersant treatment when dispersed oil ranged up to 7 mg/L (ppm).

Table 2 presents the concentrations in µg/L (ppb) for three water samples (of 44 analyzed, Tables 2 and 4) that contained C_1 to C_{10} hydrocarbons that exceeded background concentrations. These samples were collected from the research vessel Cape Henlopen used for the biology program. A copy of these results are being sent to the Biological Contractor at the University of Southern California.

Sincerely,

Clayton D. McAuliffe

Attach: Tables 1-4

cc w/attach:
M. Oguri, University of Southern California
G. P. Canevari, Exxon Research & Engineering
J. R. Gould, American Petroleum Institute

TABLE B-1. LOW-MOLECULAR-WEIGHT HYDROCARBONS DETERMINED BY GAS CHROMATOGRAPH IN WATER SAMPLES COLLECTED FROM UNDER MURBAN AND LA ROSE CRUDE OIL SLICKS OFF NEW JERSEY, OCTOBER 22 AND 23, 1979 (CHEMISTRY SHIP)

Oil					M-UT-1[a]	M-UT-1	M-T-1[b]	M-T-1	M-T-1	M-T-1	M-T-1	M-T-2	LR-UT-1[c]	LR-UT-1	LR-UT-1	LR-T-1[d]
Sample station	Bkg	Bkg	Bkg	Bkg	2.5	2.5	14.5	18.5	18.5	18.5	24.5	28.5	2.5	8.5	8.5	12.5
Sample number	1001	1002	1003	1004	1005	1006	1029	1032	1034	1036	1046	1050	1084	1089	1091	1094
Depth, m	1	3	6	9	1	3	3	0	1	3	1	0	1	1	3	1
Time	0810	0810	0810	0810	0917	0917	1130	1147	1147	1147	1220	1239	0916	0937	0937	1313
Hydrocarbons, µg/L (ppb)																
Methane	.079	.064	.072	.094	.075	.081	.110	.103	.105	.092	.109	.117	.072	.068	.077	.240
Ethane													.012	.040	.048	.010
Propane	.002			.003	.002	.004	.003	.003	.002	.005	.006	.003	.021	.048	.064	.013
Isobutane											.003		.008	.009	.013	.008
n-Butane				.001		.003	.003		.002	.004	.010	.005	.013	.020	.026	.033
Isopentane											.005	.002	.008	.006	.008	.011
n-Pentane							.005		.001		.006	.005	.008	.005	.006	.019
Cyclopentane							.003						.006	.003	.005	.007
3-Methylpentane							.002						.002		.001	.002
n-Hexane							.019	.006					.009	.005	.003	.014
Methylcyclopentane							.010						.013	.003	.002	.013
Benzene	.035	.028	.035	.038	.074	.090	.093	.045	.038	.050	.100	.068	.085	.113	.115	.145
Cyclohexane	.017	.002	.005	.006	.012	.008	.030	.006					.016	.020	.020	.025
Methylcyclohexane							.065									
Toluene	.074	.062	.060	.071	.50	.37	.77	.19	.13	.19	.52	.21	.20	.165	.160	.37
Ethylbenzene	.069	.070	.063	.058	.25	.18	.38	.124	.092	.093	.14	.102	.071	.083	.053	.090
m, p-Xylene	.35	.33	.31	.30	.88	.63	1.30	.49	.44	.43	.56	.42	.28	.26	.21	.34
o-Xylene	.17	.16	.15	.15	.58	.41	.77	.28	.24	.27	.33	.25	.19	.14	.17	.22
926 Trimethylbenzene					.044	.026	.055		.016	.020	.022	.013	.032	.060	.050	.065
1027 Trimethylbenzene	.11	.080	.080	.060	.52	.31	.80	.22	.17	.20	.27	.16	.13	.102	.12	.19
1077 Trimethylbenzene	.028				.22	.11	.31	.097	.090	.095	.094	.056	.14	.11		.26
1,2,4-Trimethylbenzene	.075	.056	.063	.056	.41	.26	.70	.22	.19	.20	.26	.18	.18	.094		.26
1197 Trimethylbenzene	.051	.050	.048	.036	.28	.11	.30	.105	.14	.115	.14	.095	.14	.11	.13	.21
Total	1.06	.90	.89	.87	3.85	2.59	5.73	1.89	1.66	1.76	2.57	1.75	1.64	1.46	1.28	2.49
Estimated oil by infrared (mg/L)[e]					.04	.04	.49	.92	.63	.44	.35	.88	2.10	.10	.07	.70
					.12	.08	2.17	1.03	.41	.36	.80	.72	.17	.10	.10	1.13

[a] M-UT-1, Untreated Murban crude oil - 1st sample run
[b] M-T-1, Dispersant treated Murban crude oil - 1st sample run
[c] LR-UT-1, Untreated La Rosa crude oil - 1st sample run
[d] LR-T-1, Dispersant treated La Rosa crude oil - 1st sample run
[e] The upper value is from sample taken just prior to sample for C_1-C_{10} hydrocarbons, the lower value is for sample taken after. The upper value sample was generally taken nearest to the C_1-C_{10} sample.

TABLE B-2. LOW-MOLECULAR-WEIGHT HYDROCARBONS FOUND IN WATER SAMPLES COLLECTED FROM BIOLOGY SHIP FROM UNDER MURBAN CRUDE OIL SLICKS, OCTOBER 22, 1979

Oil	M-UT[a]	M-UT	M-UT
Sample station	B2.5	BB2.5-3	BB2.5-3
Sample number	B5	B7	B8
Depth, m	3	1	1
Time	0935	0950	0950
Hydrocarbons, µg/L (ppb)			
Methane	.65	.084	.091
Ethane			
Propane	.035		.004
Isobutane	.015		
n-Butane	.029		
Isopentane	.019		
n-Pentane	.027		
Cyclopentane	.011		
3-Methylpentane	.004		
n-Hexane			
Methylcyclopentane			
Benzene	.062	.045	.050
Cyclohexane	.006	.005	
n-Heptane			
Methylcyclohexane			
Toluene	.31	.31	.46
Ethylbenzene	.110	.117	.13
m, p-Xylene	.35	.38	.42
o-Xylene	.18	.20	.26
926 Trimethylbenzene	.038		.025
1027 Trimethylbenzene	.121	.076	.106
1077 Trimethylbenzene	.031	.021	.046
1,2,4-Trimethylbenzene	.118	.084	.14
1197 Trimethylbenzene	.050		.050
Total	2.17	1.32	1.78

[a]M-UT, Untreated Murban crude oil

TABLE B-3. LIST OF SAMPLES ANALYZED FOR LOW-MOLECULAR-WEIGHT HYDROCARBONS THAT CONTAINED ONLY BACKGROUND CONCENTRATIONS
(See Table B-1 for Background Concentrations)

Sample Number	Sample Station	Sample Depth,m	Collection Time	Crude Oil Slick	Sample Run Number
1017	8½	1	0946		
1019	"	3	"	Untreated Murban	1st
1020	"	6	"	"	"
1021	"	9	"	"	"
1023	12½	1	1123	Treated Murban	1st
1024	"	3	"	"	"
1030	14½	3	1130	"	"
1039	22½	0	1212	Treated Murban	2nd
1041	"	1	"	"	"
1043	"	3	"	"	"
1047	24½	3	1220	"	"
1048	"	6	"	"	"
1049	"	9	"	"	"
1051	28½	1	1239	"	"
1053	"	3	"	"	"
1056	32½	1	1316	Untreated Murban	2nd
1059	34½	1	1325	"	"
1066	42½	1	1420	Treated Murban	3rd
1067	"	3	"	"	"
1070	44½	1	1438	"	"
1071	"	3	"	"	"
1074	48½	1	1458	"	"
1075	"	3	1458	"	"
1085	2½	1	0916	Untreated La Rosa	1st
1086	"	3	"	"	"
1095	12½	3	1313	Treated La Rosa	1st
1096	"	6	"	"	"
1097	"	9	"	"	"
1101	22½	3	1404	Treated La Rosa	2nd
1102	"	6	"	"	"
1103	"	9	"	"	"
1104	28½	1	1439	"	"
1105	"	3	"	"	"
1106	"	6	"	"	"
1107	"	9	"	"	"
1108	32½	1	1511	Untreated La Rosa	2nd
1109	"	3	"	"	"
1110	"	6		"	"
1111	"	9	"	"	"
1112	38½	1	1538	"	"
1113	"	3	"	"	"
1114	42½	0	1610	Treated La Rosa	3rd
1115	"	1	"	"	"
1117	"	3	"	"	"
1118	"	6	"	"	"
1119	"	9	"	"	"

TABLE B-4. LIST OF SAMPLES ANALYZED FOR LOW-MOLECULAR-WEIGHT HYDROCARBONS THAT CONTAINED ONLY BACKGROUND CONCENTRATIONS (See Table B-1 for Background Concentrations)

Sample Number	Sampler	Station Number	Sample Depth,m	Collection Time	Crude Oil Slick
B4	Niskin	B2½	1	0935	Untreated Murban
B7	Pump	BB2½-3	1	0950	"
B9	"	"	3	0950	"
B11	Niskin	B3½	1	1042	Open water (control)
B17	Niskin	B4½	1	1129	Treated Murban
B18	"	"	3	"	"
B19	"	"	6	"	"
B20	Pump	BB4½-3	1	1136	Treated Murban
B22	"	"	3	"	"
B24	Niskin	B6½	1	1305	Treated Murban
B25	"	"	3	"	"
B26	"	"	6	"	"
B27	Niskin	B7½	1	1416	Open water (control)
B29	Niskin	B8½	1	1412	Treated Murban
B30	"	"	3	"	"
B31	"	"	6	"	"
B36	Niskin	B1½	1	0807	Open water (control)
B37	"	"	3	"	"
B38	Niskin	B2½	1	0924	Untreated La Rosa
B39	"	"	3	"	"
B40	"	"	6	"	"
B41	Pump	BB2½-3	1	0935	Untreated La Rosa
B43	"	"	3	"	"
B46	Niskin	B3½	1	1018	Open water (control)
B50	Niskin	B5½	1	1042	Untreated La Rosa
B51	"	"	3	"	"
B53	Niskin	B4½	1	1412	Treated La Rosa
B54	"	"	3	"	"
B55	"	"	6	"	"
B56	Pump	BB4½-3	1	1344	Treated La Rosa
B57	"	"	1	"	"
B58	Pump	BB4½-12	3	1344	Treated La Rosa
B59	"	"	3	"	"
B60	Niskin	B6½	1	1500	Treated La Rosa
B65	"	"	3	"	"
B63	"	"	6	"	"
B64	Niskin	B7½	1	1515	Open water (control)
B66	Niskin	B8½	1	1611	Treated La Rosa
B67	"	"	3	"	"
B68	"	"	6	"	"
B69	Niskin	B9½	1	1646	Untreated La Rosa